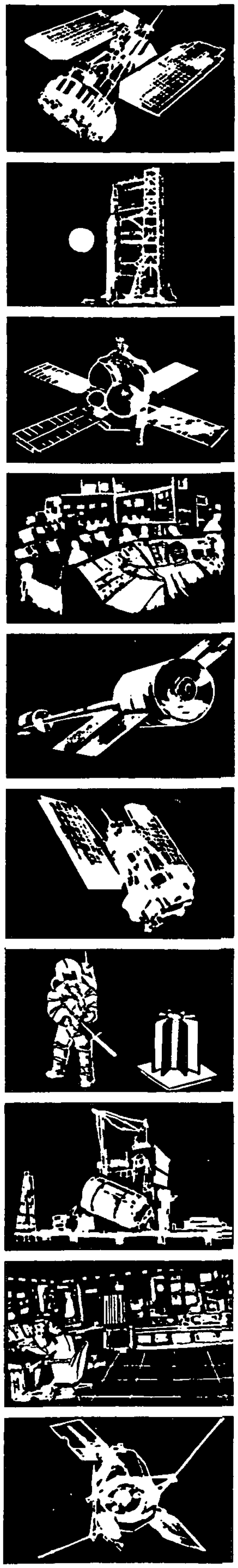
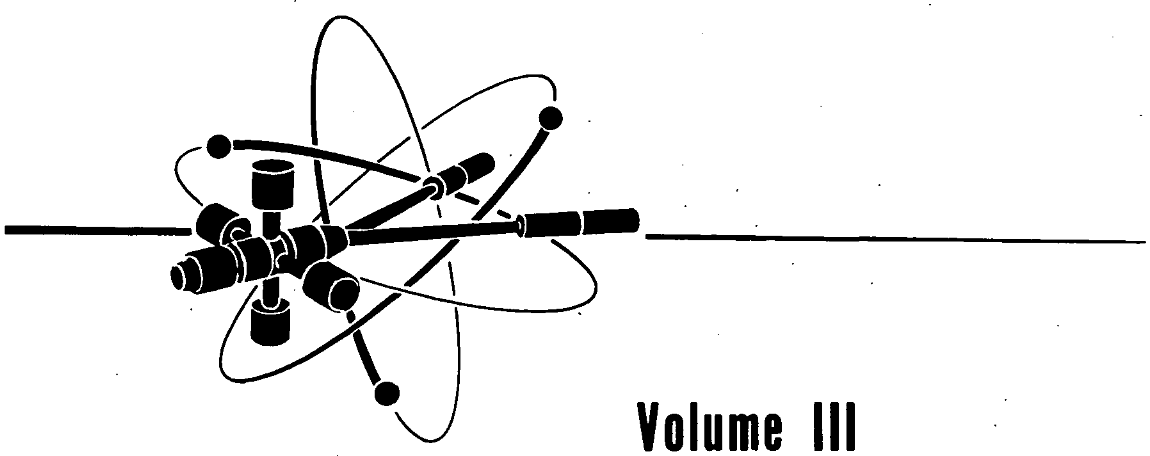
N73-11696

72SD4201-3-1

SPACE DIVISION



manned space flight nuclear system safety



Volume III

REACTOR SYSTEM PRELIMINARY NUCLEAR SAFETY ANALYSIS

Part 1

REFERENCE DESIGN DOCUMENT (RDD)

GENERAL ELECTRIC

DOCUMENT NO. 72SD4201-3-1
JANUARY 1972

FINAL REPORT

MANNED SPACE FLIGHT NUCLEAR SYSTEM SAFETY

VOLUME III - REACTOR SYSTEM PRELIMINARY NUCLEAR SAFETY ANALYSIS
PART 1 - REFERENCE DESIGN DOCUMENT (RDD)

PERFORMED UNDER

CONTRACT NO. NAS8-26283

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

CONDUCTED BY

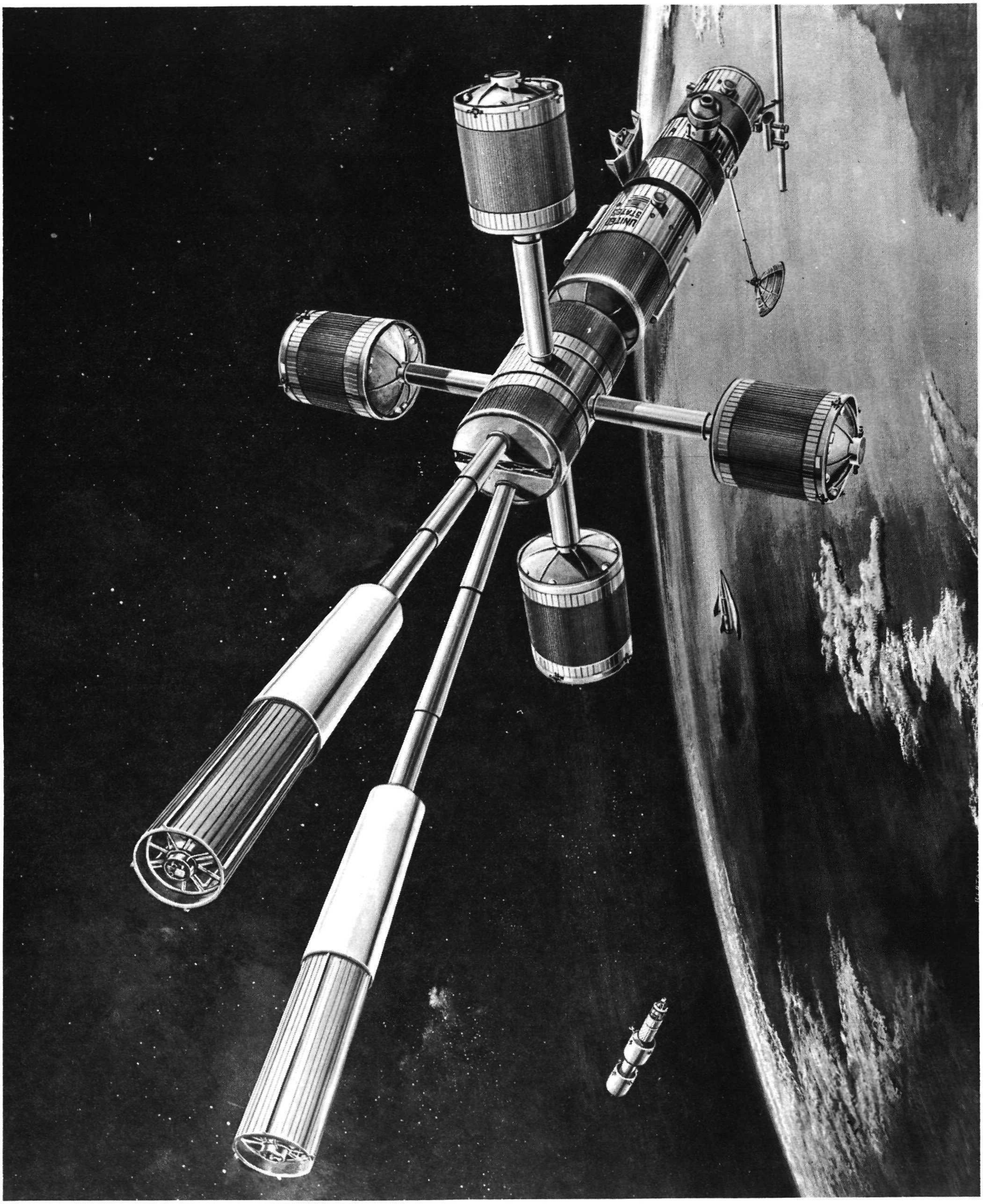
SPACE DIVISION
Valley Forge Space Center
P. O. Box 8555 • Philadelphia, Penna. 19101

GENERAL ELECTRIC

ABSTRACT

The Reference Design Document, Volume III Part 1, of the Preliminary Safety Analysis Report (PSAR) - Reactor System provides the basic design and operations data used in the nuclear safety analysis of the Reactor Power Module as applied to a Space Base program. A description of the power module systems, facilities, launch vehicle and mission operations, as defined in NASA Phase A Space Base studies is included.

Each of two Zirconium Hydride Reactor Brayton power modules provides 50 kWe for the nominal 50 man Space Base. The INT-21 is the prime launch vehicle. Resupply to the 500 km orbit over the ten year mission is provided by the Space Shuttle. At the end of the power module lifetime (nominally five years), a reactor disposal system is deployed for boost into a 990 km high altitude (long decay time) earth orbit.


UNITED STATES

FOREWORD

The establishment and operation of large manned space facilities in earth orbit would constitute a significant step forward in space. Such long duration programs with orbital stay times of up to ten years would benefit the earth's populace and the scientific community by providing:

1. A flexible tool for scientific research.
2. A permanent base for earth oriented applications.
3. A foundation for the future exploration of our universe.

Specifically, the NASA objectives include earth surveys and scientific disciplines of astronomy, bioscience, chemistry, physics and biomedicine, as well as the development of technology for space and earth applications.

Operational and design requirements, of large manned space vehicles, differ from those of the Mercury, Gemini, and Apollo programs. Of particular interest are the radiation survivability and nuclear safety requirements imposed by nuclear power reactors and isotopes and the long term interaction with the natural radiation environment.

The General Electric Company under contract to NASA-MSFC (NAS8-26283) has performed a study entitled "Space Base Nuclear System Safety" for the express purposes of addressing the nuclear considerations involved in manned earth orbital missions. The study addresses both operational and general earth populace and ecological nuclear safety aspects. The primary objective is to identify and evaluate the potential and inherent radiological hazards associated with such missions and recommend approaches for hazard elimination or reduction of risk.

Work performed utilized the Phase A Space Base designs developed for NASA by North American Rockwell and McDonnell Douglas as baseline documentation.

The study was sponsored jointly by NASA's Office of Manned Space Flight, Office of Advanced Research and Technology, and Aerospace Safety Research and Data Institute. It was performed for NASA's George C. Marshall Space Flight Center under the direction of Mr. Walter H. Stafford of the Advanced Systems Analysis Office. He was assisted by a joint NASA and AEC advisory group, chaired by Mr. Herbert Schaefer of NASA's Office of Manned Space Flight.

The results of the study are presented in seven volumes, the titles of which are listed in Table A. A cross-reference matrix of the subjects covered in the various volumes is presented in Table B.

Table A. Manned Space Flight Nuclear System Safety Documentation

Volume		Document No.
I	Executive Summary	
Part 1	*Space Base Nuclear Safety*	72SD4201-1-1
Part 2	Space Shuttle Nuclear Safety	72SD4201-1-2
II	Space Base Preliminary Nuclear Safety Analysis	
Part 1	Nuclear Safety Analysis (PSAR)	72SD4201-2-1
Part 1A	Appendix-Alternate Reactor Data (CRD)	72SD4201-2-1A
III	Reactor System Preliminary Nuclear Safety Analysis	
Part 1	Reference Design Document (RDD)	72SD4201-3-1
Part 2	Accident Model Document (AMD)	72SD4201-3-2
Part 2A	Accident Model Document - Appendix	72SD4201-3-2A
Part 3	Nuclear Safety Analysis Document (NSAD)	72SD4201-3-3
IV	Space Shuttle Nuclear System Transportation	
Part 1	Space Shuttle Nuclear Safety	72SD4201-4-1
Part 2	Terrestrial Nuclear Safety Analysis	72SD4201-4-2
V	Nuclear System Safety Guidelines	
Part 1	Space Base Nuclear Safety	72SD4201-5-1
Part 2	Space Shuttle/Nuclear Payloads Safety	72SD4201-5-2
VI	Space Base Nuclear System Safety Plan	72SD4201-6
VII	Literature Review	
Part 1	Literature Search and Evaluation	72SD4201-7-1
Part 2	ASRDI Forms	72SD4201-7-2*

*Limited distribution

This study employs the International system of units and where appropriate the equivalent English units are specified in brackets. A list of Conversion Factors and a Glossary of Terms is included in the back of each volume.

Table B. Study Area Cross Reference

* □ 4 PRIMARY DISCUSSION

○ SUMMARY OR SUPPLEMENTAL DISCUSSION

*Section number is included where appropriate

STUDY AREAS	VOL I — 72SD4201-1 — Part 1 Space Base - Executive Summary	VOL I — Part 2 Space Shuttle - Executive Summary	VOL II — 72SD4201-2 — Part 1 PSAR-Space Base	VOL II — Part 2 Appendix (CRD)	VOL III — 72SD4201-3 — Part 1 RDD-Reactor System, Space Base	VOL III — Part 2 AMD-Reactor System	VOL III — Part 2A AMD Appendix	VOL III — Part 3 NSAD-Reactor System	VOL IV — 72SD4201-4 — Part 1 Space Shuttle Nuclear Safety	VOL IV — Part 2 Terrestrial Nuclear Safety Analysis	VOL V — 72SD4201-5 — Part 1 Guidelines - Space Base	VOL V — Part 2 Guidelines - Space Shuttle	VOL VI — 72SD4201-6 — System Safety Plan	VOL VII — 72SD4201-7 — Part 1 Literature Search and Evaluation	VOL VII — Part 2 ASRDI Forms
SPACE BASE PROGRAM															
Reference Vehicle Data	○		□ 3												
Radiation Limits	○		□ 4,A					○	○						
Radiation Environment/Hazards	○		□ 6			□ 3-5							○ 5		
Radiation Effects	○		□ 6,A												
Mission Support Nuclear Safety	○		□ 5										○ 6		
Orbital Operations Nuclear Safety	○		□ 6,7						○ 3-5						
Design & Operational Considerations	○		□ 5,7					○	○ 3-5						
Guidelines & Requirements	○		○					○			□	○	○ 5		
Reactor System Studies	○		□ 7	□											
Terrestrial Safety Analysis	○														
Reference Design					□				○ ABC						
Accident Models & Source Terms						□	□			○ 2,3					
Risk Analysis								□		○ 2,3					
System Safety Plans													□		
Technology Development Required	○		□ 8					○					○ 7,8		
SPACE SHUTTLE PROGRAM															
Reference Vehicle Data		○							□ ABC						
Nuclear Payload Integration		○							□ 3-5						
Design & Operational Considerations		○	○						□ 3-5						
Guidelines and Requirements		○	○						○ 3-6		○	□			
Terrestrial Safety Analysis		○			○	○		○	○ 6	□					
LITERATURE REVIEW DATA															
Approach and Cross Index														□	
ASRDI Forms															□

ABBREVIATIONS

ADM	Add-on Disposal Modules
AEC	Atomic Energy Commission
ALS	Advanced Logistic System (Space Shuttle)
AMD	Accident Model Document
ASRDI	Aerospace Safety Research Data Institute
BOL	Beginning of Life
BPCL	Brayton Power Conversion Loop
BRU	Brayton Rotating Unit
DOD	Department of Defense
DOT	Department of Transportation
ECLS	Environmental Control and Life Support
EM	Electro Magnetic
EOD	Earth Orbital Decay
EOL	End of Life
EOM	End-of-Mission
EPS	Electrical Power System
ETR	Eastern Test Range
EVA	Extra Vehicular Activity
FC	Fuel Capsule
FPE	Functional Program Element
G&C	Guidance and Control
GSE	Ground Support Equipment
HX	Heat Exchanger
ICRP	International Committee on Radiation Protection
IDM	Integral Disposal Module
INT-21	Intermediate Saturn Stages
IR	Infrared
IRV	Isotope Re-Entry Vehicle
IU	Instrument Unit
IVA	Intra Vehicular Activity
KSC	Kennedy Space Center
LCC	Launch Control Center
LD	Lethal Dose (% Probability)
LOX	Liquid Oxygen
LV	Launch Vehicle
MCC	Mission Control Center
MDAC	McDonnell Douglas Corporation
MHW	Multi-Hundred Watt
ML	Mobile Launcher
MPC	Maximum Permissible Concentration
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSS	Mobile Service Structure
NA	Non-Applicable
NAB	Nuclear Assembly Building
NAR	North American Rockwell
NASA	National Aeronautics and Space Administration
NC	Non-Credible
NCRP	National Committee on Radiation Protection
NSAD	Nuclear Safety Analysis Document
OPSD	Orbital Propellant Storage Depot
ORNL	Oak Ridge National Laboratory
PCS	Power Conversion System
PM	Power Module
PSAR	Preliminary Safety Analysis Report
RAD	Radiation Absorbed Dose
RCS	Reaction Control System
RDD	Reference Design Document
REM	Roentgen Equivalent Man
RMU	Remote Maneuvering Unit
RNS	Reusable Nuclear Shuttle
R/S	Reactor/Shield
RSO	Radiation Safety Officer
RTG	Radioisotope Thermoelectric Generator
SB	Space Base
SAR	Safety Analysis Report
SEHX	Separable Heat Exchanger
S-IC	First Stage of Saturn V
S-II	Second Stage of Saturn V
SNAP	Space Nuclear Auxiliary Power
SNAPTRAN	Space Nuclear Auxiliary Power Transient
TAC	Turbine Alternator Compressor
TEM	Thermoelectric Electro Magnetic Pump
TLD	Thermo Luminescent Dosimeter
USAF	United States Air Force
VAB	Vehicle Assembly Building

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont)

LIST OF ILLUSTRATIONS

SECTION 1
INTRODUCTION

KEY CONTRIBUTORS

J.A. GARATE
E.E. GERRELS

SECTION 1
INTRODUCTION

The Preliminary Safety Analysis Report (PSAR) - Reactor System presents a comprehensive assessment of public and ecological safety of the Zirconium-Hydride (ZrH) Brayton Cycle Reactor Electrical Power System as applied to a Space Base Program. The reference power system was derived from the Phase A Space Base studies recently performed for NASA by MDAC and NAR (References 1-1 and 1-2).

The PSAR is presented in three separate documents as follows:

Volume III, Part 1 - Reference Design Document (RDD)

Volume III, Part 2 - Accident Model Document (AMD)

Volume III, Part 3 - Nuclear Safety Analysis Document (NSAD)

Figure 1-1 illustrates the basic logic and structure of the PSAR.

This document, the RDD, contains a description of the ZrH Reactor Electrical Power System (EPS), related hardware, and mission and operational data to provide all pertinent design information and required performance of the nuclear safety analysis. Every effort has been made to present only that information considered germane to the analysis.

The other two documents in the series serve: (1) to identify and estimate the possibility of occurrence of potential mission-related failure modes and sequences which can lead to public nuclear safety hazards (Part II AMD); (2) to describe the radiological consequences that could result from the failures and present design and/or operational features that could minimize or eliminate the potential hazards (Part III, NSAD).

The analysis performed in this PSAR is concerned with public rather than crew safety. The potential hazards imposed by the reactor power modules on the crew are presented in Volume II, PSAR-Space Base.

The Space Base reference design ZrH power module employs a Brayton cycle conversion system. It is expected that the application of other conversion systems with different manned spacecraft configurations should not significantly affect the results and overall conclusions of the study. The changes which may result (failure modes, probabilities and modified source terms) can be rather easily factored into the analysis and the relative effects determined. Therefore, the results of this study can serve as a point of departure for the nuclear safety analysis of reactor powerplants on future manned space missions.

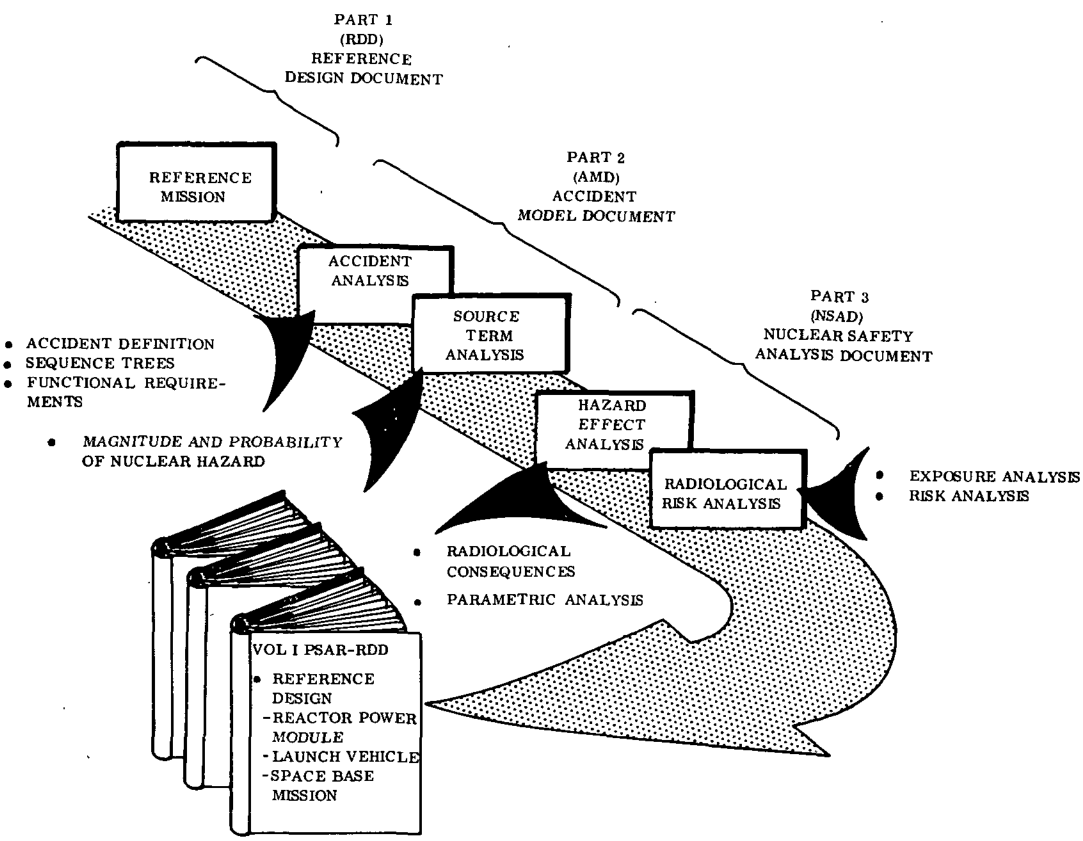


Figure 1-1. PSAR Logic

REFERENCES

1-1 "Space Base Concept Data," Volume I-VIII, MDC-G0576, McDonnell Douglas, June 1970.

1-2 "Space Base Definition," Volume I-III, MSC-00721 (SD70-160), North American Rockwell, July 1970.

SECTION 2
NUCLEAR ELECTRICAL POWER SYSTEM

KEY CONTRIBUTORS

A. CARUVANA
J.A. GARATE

SECTION 2
NUCLEAR ELECTRICAL POWER SYSTEM

Electrical power requirements for the Space Base are supplied by two independent, ZrH reactor power modules providing a total of 100 kWe as illustrated in Figure 2-1. The baseline design is that specified by MDAC in recent Space Base Phase A studies (Reference 2-1). To supply this net power, each reactor in the Electrical Power System (EPS) is rated at 600 kWt but normally operates at 330 kWt. Each reactor is coupled to three Brayton cycle power conversion systems - one operating and two on stand-by, as shown in Figure 2-2. During normal operation, one Brayton unit delivers 50 kW of net electrical power. Nominal operating life of each Brayton unit is assumed to be 2.5 years whereas reactor lifetimes are assumed to be 5 years.

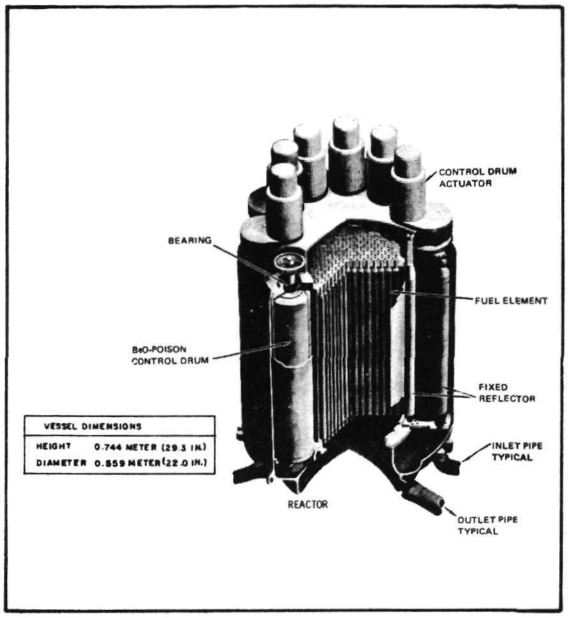
The EPS is divided into four major subsystems as illustrated in the simplified schematic (Figure 2-2).

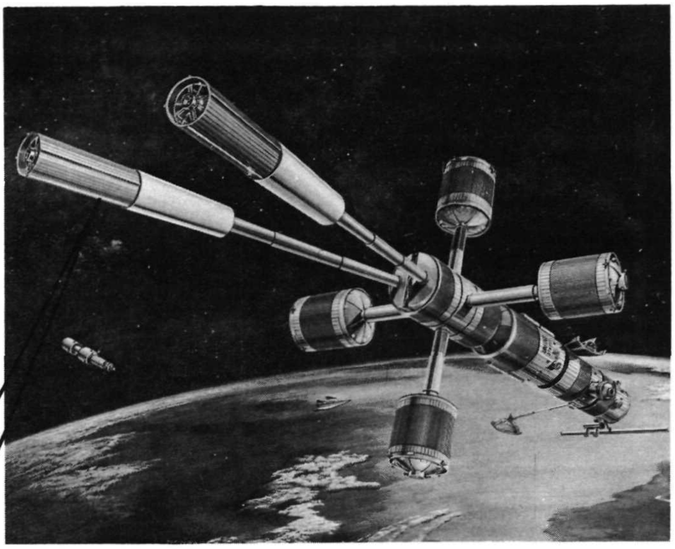
1. Reactor Primary NaK Loop
2. Reactor Intermediate NaK Loop
3. Brayton Gas Power Conversion Loop
4. Brayton Heat Rejection Loop

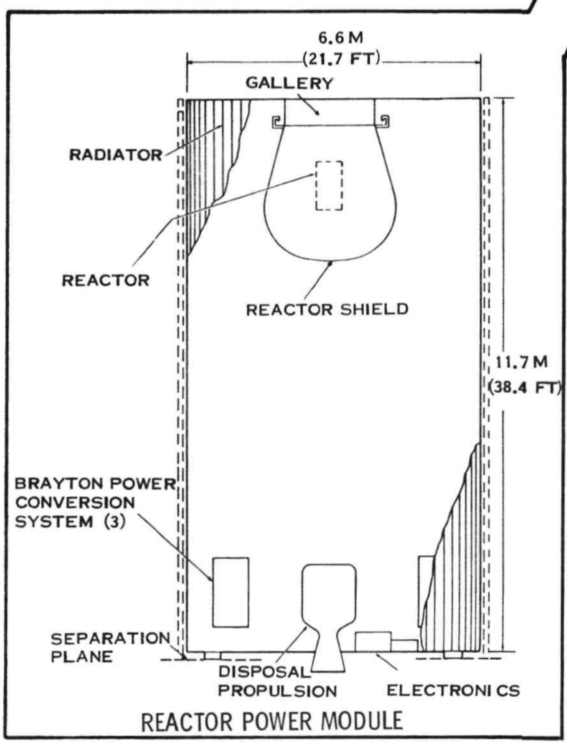
A summary of the key reactor Brayton system characteristics is given in Table 2-1. The mass distribution within one reactor power module (EPS plus reactor system) is presented in Table 2-2.

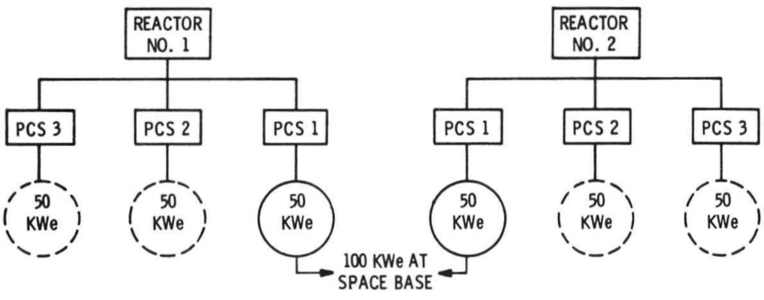
2.1 <u>REACTOR PRIMARY NaK LOOP</u>

The Primary NaK Loop transfers the heat from the reactor to the NaK-to-NaK heat exchanger located in the gallery on the opposite side of the Space Base interface. This allows the reactor shield to be placed between the activated NaK inventory and the Space Base, thus reducing the overall radiation levels to the Space Base and to the power conversion system components.



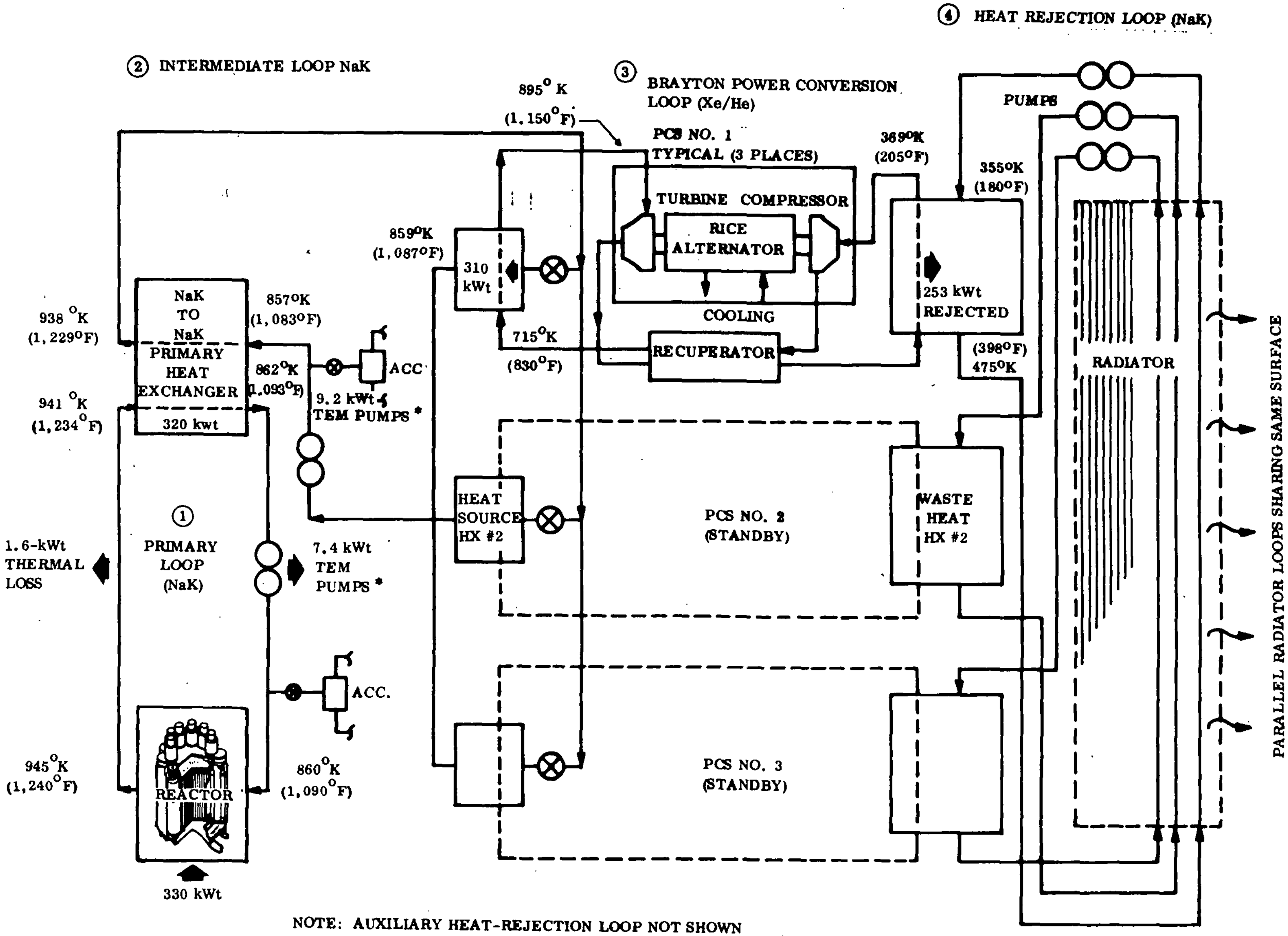






ITEM	CONCEPT REMARKS
REACTOR	2 Z_RH, 295 FUEL ELEMENTS
CONTROL	10 DRUMS
POWER CONVERSION	3-50 KW_E BRAYTON UNITS/REACTOR
NORMAL POWER LEVEL	330 KW_T
EMERG POWER LEVEL	600 KW_T (ASSUMED FOR STUDY)
SHIELD	SHAPED 4 π LiH
RADIATION LEVELS	1 MR/HR SB INTERFACE
LIFETIME	5 YEARS

Figure 2-1. Reactor Power Module Details



NOTE: AUXILIARY HEAT-REJECTION LOOP NOT SHOWN

*THERMOELECTRIC ELECTROMAGNETIC (TEM) PUMPS ARE IN THE SYSTEM PER REFERENCE 2-1. MORE RECENT CONCEPTS EMPLOY ELECTROMAGNETIC (EM) PUMPS.

Figure 2-2. Schematic of Reactor/Brayton Cycle System

Table 2-1. ZrH Reactor Brayton System Characteristics (Each of Two-50 kWe Sources)

		International Units	English Units
EPS			
1.	Net conditioned output power (kWe)	50.0	
2.	Conditioning and distribution losses (kWe)	8.2	
3.	Parasitic pumping and control losses (kWe)	7.8	
4.	Gross raw power rating (kWe)	66	
5.	Installed PCS modules (active/standby)	1/2	
6.	PCS design wearout life goal (yr)	2.5	
7.	Reactor thermal power (kWt)	330	
8.	Prime radiator heat rejection (kWt)	253	
9.	Auxiliary (low-temperature) radiator rejection (kWt)	17.6	
10.	Radiator area (prime)	$242 m^2$	$2400 ft^2$
11.	Radiator area (auxiliary)	$18.6 m^2$	$220 ft^2$
12.	Average system life (yr)	5	
13.	Reactor temperature (inlet/outlet)	860/945°K	1090/1240°F
14.	Conversion efficiency (%)	17.7	
PCS			
1.	Working gas	Xe/He	
2.	Turbine inlet temperature	895°K	1,150°F
3.	Compressor inlet temperature	369°K	205°F
4.	Shaft speed/frequency (rpm/Hz)	24000/400	
5.	Cycle heat input (kWt)	310	
6.	Cycle efficiency (%)	21.3	
7.	Turbine inlet pressure	$99.4 \times 10^4 N/m^2$	144.4 psia
8.	Recuperator effectiveness	0.92	
9.	Pressure loss factor (β)	0.96	
10.	Compressor/turbine efficiency (%)	85.6/90.0	
11.	Compressor/turbine pressure ratios	1.74/1.67	
Radiator (Prime)			
1.	Coating	Z-93	
2.	Coating α/ϵ	0.25	
3.	Sink temperature	244°K	-20°F
4.	Fluid	NaK	
5.	Number of active/standby loops	1/2	
6.	Inlet/outlet temperature	475/355°K	398/180°F

Table 2-2. Reactor/Brayton System Mass

Item	Mass (kg)	Mass (lb)
Reactor	830	1,830
Primary loop	297	655
Shield (non-optimized)	18,413	40,600
Intermediate loop	340	750
Power conversion systems (3)	1,848	4,074
Turbine-alternator-compressor	198	437
Heat source heat exchanger	91	201
Recuperator	122	268
Heat sink heat exchanger	54	118
Miscellaneous	151	334
Total (each)	616	1,358
Electrical/electronics (3)	671	1,479
Heat rejection loop	268	592
Radiator/radiator structure	1,700	3,750
Structural cone and mounting brackets	454	1,000
Thermal shroud, tracks, and actuators	590	1,300
Docking equipment	136	300
Disposal propulsion (15%)	3,830	8,450
Subtotal	29,377	64,780
Contingency (10%)	2,938	6,478
Total	32,315	71,258

The primary loop flow is supplied by redundant thermoelectric powered electromagnetic (TEM) pumps which derive power by diverting 7.4 kWt from the loop flow. A description of the reference design ZrH reactor is contained in Section 2.5.

2.2 REACTOR INTERMEDIATE NaK LOOP

The Intermediate NaK Loop transfers the heat from the primary loop to the Brayton Power Conversion Loop via a NaK-to-gas (Xe/He) heat exchanger located in the Power Conversion System (PCS) module. The intermediate loop also employs redundant TEM pumps to circulate the NaK through the loop. These pumps also divert power from the loop (9.2 kWt) as its source of energy. The standby PCS units are valved out of the loop to reduce pumping power requirements.

2.3 BRAYTON GAS POWER CONVERSION LOOP

The Power Conversion Loop, referred to as the Brayton PCS, contains five major components:

1. Heat Source Heat Exchanger
2. Brayton Rotating Unit - (Turbine-Alternator-Compressor)
3. Recuperator
4. Gas Management System
5. Waste Heat - Heat Exchanger

The reference Brayton Rotating Unit (BRU) consists of a single-stage radial turbine, a two-pole Rice alternator and a single stage radial compressor mounted on a common shaft rotating at 24,000 rpm. The BRU with hydrodynamically operating bearings and other components are to be capable of zero g to 3 g operation in any orientation. The working gas of the BRU is an Xe/He mixture with a turbine inlet temperature of 895°K (1150°F). A relatively high temperature (approximately 900°K) NaK-to-gas heat exchanger is employed in the upstream end of the PCS and a low temperature (approximately 500°K) gas-to-NaK heat exchanger is used to supply waste heat to the radiator. Each PCS heat rejection system is designed such that its heat rejection loop is hydraulically independent of each other. Typical system flow as shown in Figure 2-2 is Xe/He from the NaK-gas heat exchanger to the turbine from which the waste heat is ducted to the recuperator then to the waste heat-heat exchanger and then to the compressor inlet. The compressed Xe/He mixture from the compressor discharge then flows through the recuperator and back to the gas-to-NaK heat exchanger.

Load control of the PCS is accomplished with the plant furnishing average power equal to the average primary bus load and then utilizing a battery/inverter to furnish peak power and absorb excess power. The constant power level approach results in a simple control system with only a small part of the components actually active during normal operation. The reference Gas Management System (Reference 2-2) is shown in Figure 2-3 and contains all mechanisms required to meter and cycle working fluid for pressure adjustment and leakage makeup. The voltage and frequency controls are the only continuously modulating components in the system. The other components remain unpowered except to compensate for leakage and to provide shutdown and startup functions.

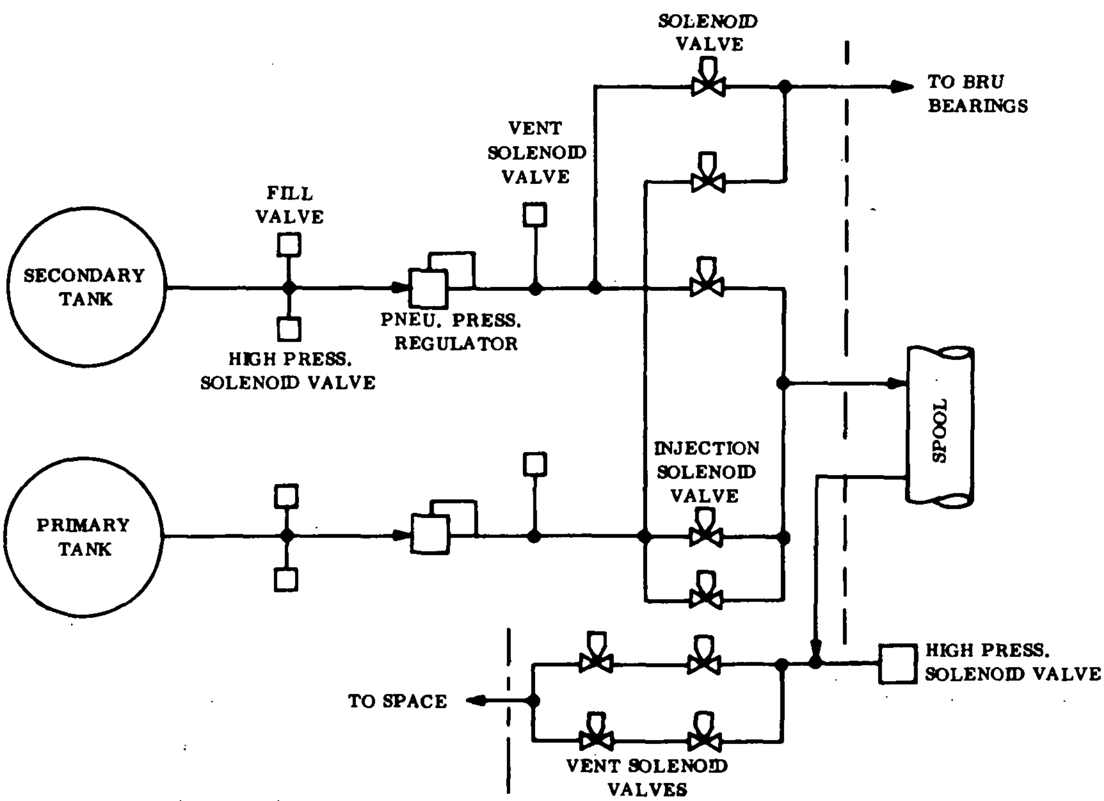


Figure 2-3. Gas Management System Schematic

Power, generated by the PCS units, is paralleled at the source buses to load centers throughout the Space Base (Figure 2-4).

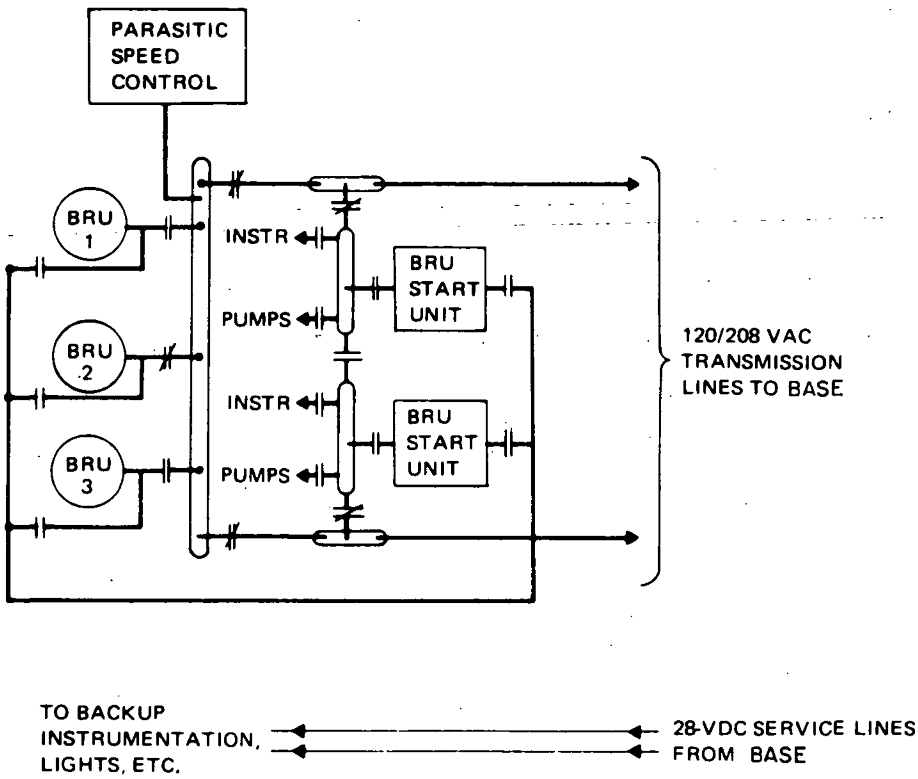


Figure 2-4. Brayton System Electric Power Distribution

2.4 BRAYTON HEAT REJECTION LOOP

Waste heat is rejected from the power conversion loop to the heat rejection loop via a waste heat (gas-to-NaK) heat exchanger. Each PCS heat rejection system is designed such that its heat rejection loop is hydraulically independent of each other. Each PCS is designed with its own waste - heat exchanger, independent piping loop, and 400 Hz motor driven centrifugal pump. The radiator is 6.6 m (260 in.) in diameter and 11.7 m (38.4 ft) in length resulting in a total radiator area of 242 m^2 (2600 ft^2) for a 50 kWe net unit. Each of the three PCS' has its own loop on the radiator on a common fin sharing basis. The radiator is equipped with a retractable shroud to prevent freezing of the NaK during non-operational periods of the PCS. Cooling the alternator and electronic accessories located in the power conversion system is accomplished by utilizing an 18.6 m^2 (200 ft^2 auxiliary radiator.

The EPS radiator serves multi-functional purposes. The PCS' are located within the radiator as is the shielded reactor. Rendezvous equipment and docking adaptors are provided at both ends of the power module including attachments at the reactor-shield interface.

The radiator in its present concept, is also attached to a disposal system capable of boosting the entire power module into a long life orbit. Design details on this system are presented in Section 3.

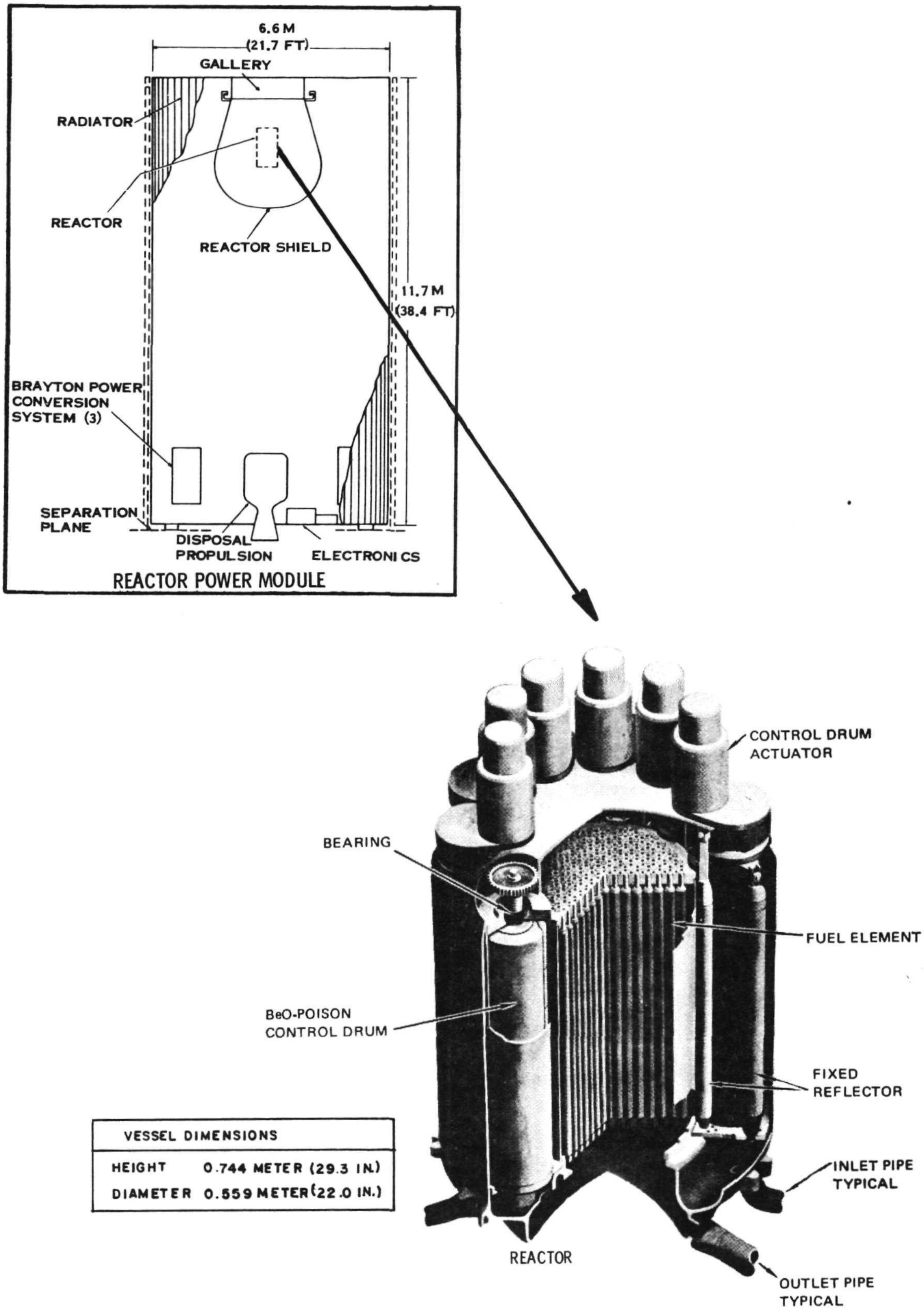
2.5 ZIRCONIUM HYDRIDE REACTOR

The reference zirconium hydride reactor situated inside the outer end of the radiator is designed to operate over a wide range of temperature and power levels and is completely surrounded by shielding. The reactor consists of three major subassemblies; the core, vessel, and reflector assemblies. A cutaway view of the reactor is shown in Figure 2-5 and some of its key design features are shown in Table 2-3.

2.5.1 REACTOR CORE

The reactor core consists of a triangular pitch array of 295 fuel elements and has a 0.29 m (11.4 in.) diameter.

The fuel elements (Figure 2-6) consist of an alloy of 10.5 wt% fully enriched uranium in zirconium which is massively hydrided to provide neutron moderation. The hydrogen content of the fuel is 6.3×10^{22} atoms/cm^3 which is about the same as the hydrogen content in cold water. The fuel elements are contained within 0.38 mm (0.015 in.) thick nickel alloy cladding tubes which protect them from the NaK coolant and contain the fission products and hydrogen moderator. Because of the significant permeation rate of hydrogen through the bare cladding, a thin glass barrier is fused to the inside of the cladding tubes. Small clearances are provided between the fuel element and cladding to allow for radiation-induced growth of the fuel. The fuel elements have a helical fin to encourage coolant channel mixing, to reduce fuel element bowing, to lower adjoining fuel element contact stresses, and to minimize coolant flow channel area changes between the elements. Variable spacing is used to furnish each element with coolant flow proportional to its generated power.



VESSEL DIMENSIONS	
HEIGHT	0.744 METER (29.3 IN.)
DIAMETER	0.559 METER (22.0 IN.)

Figure 2-5. Zirconium Hydride Reactor

Table 2-3. Reference ZrH Reactor Design Data

Number of fuel elements	295
Fuel element length	0.427 m (16.825 in.)
Fuel element outside diameter	14.7 to 15.2 mm (0.578 to 0.600 in.)
Clearance between fuel elements	Variable
Core diameter	0.290 m (11.40 in.)
Cladding material	Hastelloy N or Incoloy 800
Hydrogen barrier material	SCB-1
Fuel hydrogen content	$6.3 \times 10^{22} \frac{\text{H Atoms}}{\text{cm}^3}$
Fuel material	U-ZrH
Fuel uranium content	10.67 percent
Fuel-to-clad gap width	Variable
Control-drum type	Reflector-poison
Number of active control drums	10
Control drum materials	BeO/Ta-10 W
Control drum diameter	0.114 m (4.50 in.)
Reactor vessel outside diameter	0.559 m (22.00 in.)
Reactor vessel height	0.744 m (29.30 in.)
Thermal power	330 kWt
Outlet temperature	945^{o}K (1240^{o}F)
Temperature rise	$\sim 338^{o}$K ($\sim 150^{o}$F)
Reactor lifetime	5 years
Peak fuel temperature	1044^{o}K (1420^{o}F)
Core burnable poison material	Gd-155
Peak control-drum temperature	1100^{o}K (1520^{o}F)
Peak drum bearing temperature	905^{o}K (1350^{o}F)
Coolant	NaK-78

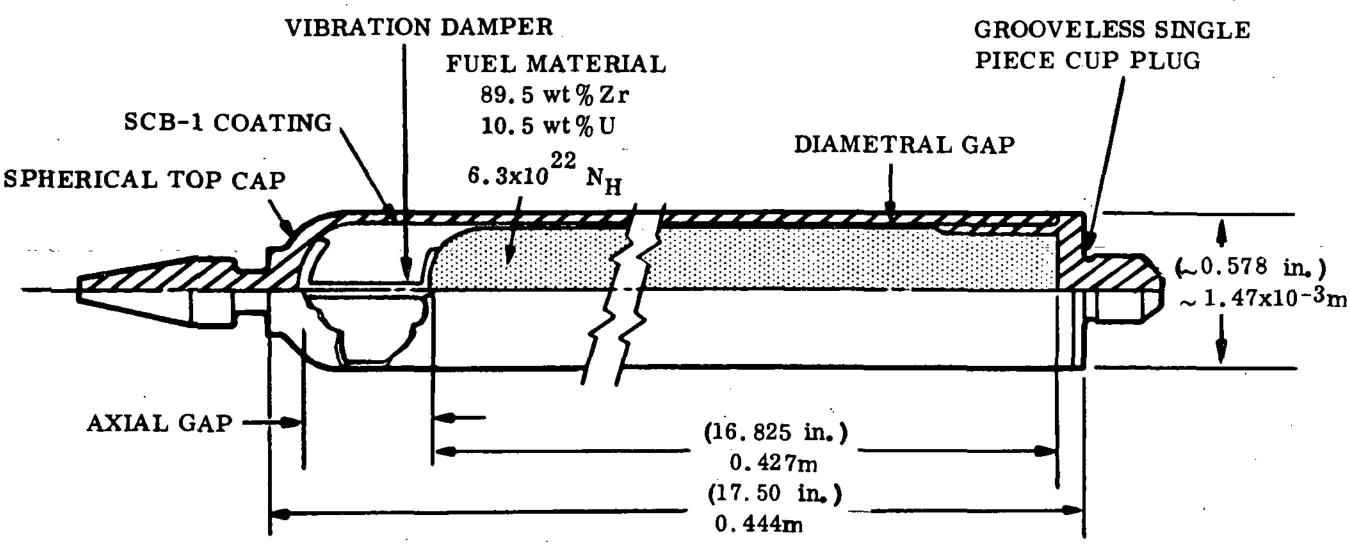


Figure 2-6. Reference Fuel Element

2.5.2 REFLECTOR ASSEMBLY

The reflector assembly consists of the 10 neutron control drums, drive mechanisms, instrumentation and mounting structure uniformly spaced around the core assembly. Rotation of the drums provides the degree of neutron leakage required to maintain the reactor operating at desired levels. Each reactor control drum (Figure 2-7) is 0.114 m (4.5 in.) in diameter and 0.457 m (18 in.) long. The drum consists of beryllium oxide (BeO) reflector material fastened to a neutron-absorbing metal (Ta-10W which also serves as the main structural member. The drum is supported by self-aligning ball-and-socket-type bearings. The control-drum shaft and the bearing socket are coated with flame-sprayed alumina which provides a low-friction surface when in contact with the solid graphite ball. Drum rotation is produced by a stepper motor operating through an integral 6:1 gear set (Figure 2-8). In the fully shutdown position the gear teeth are dis-engaged by a cam lockout device to prevent drum rotation due to launch acceleration. In addition to the moveable drums, fixed cylindrical BeO reflectors are located between each of the reactor vessel dry wells for reactivity enhancement.

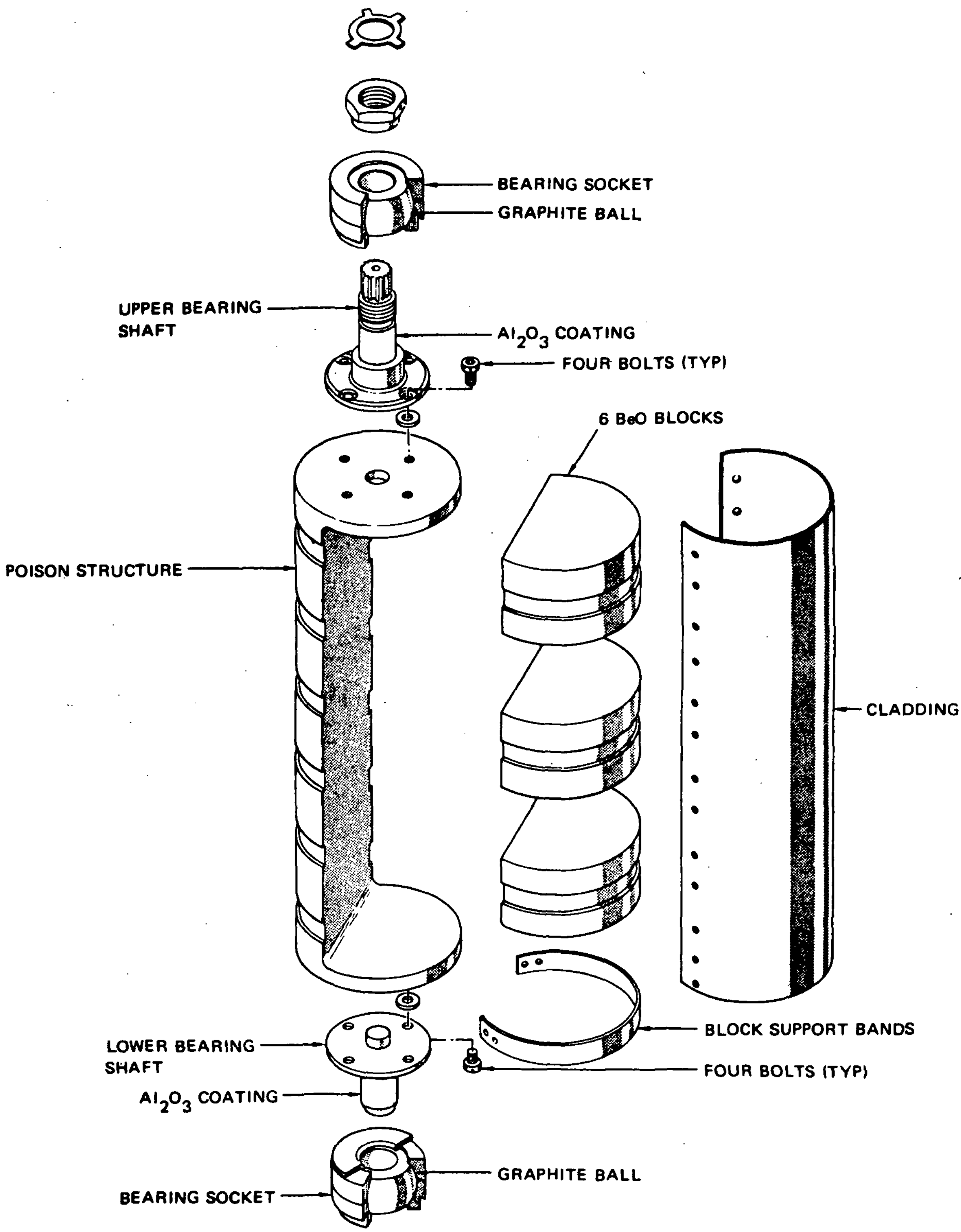


Figure 2-7. ZrH Reactor Control Drum and Bearings

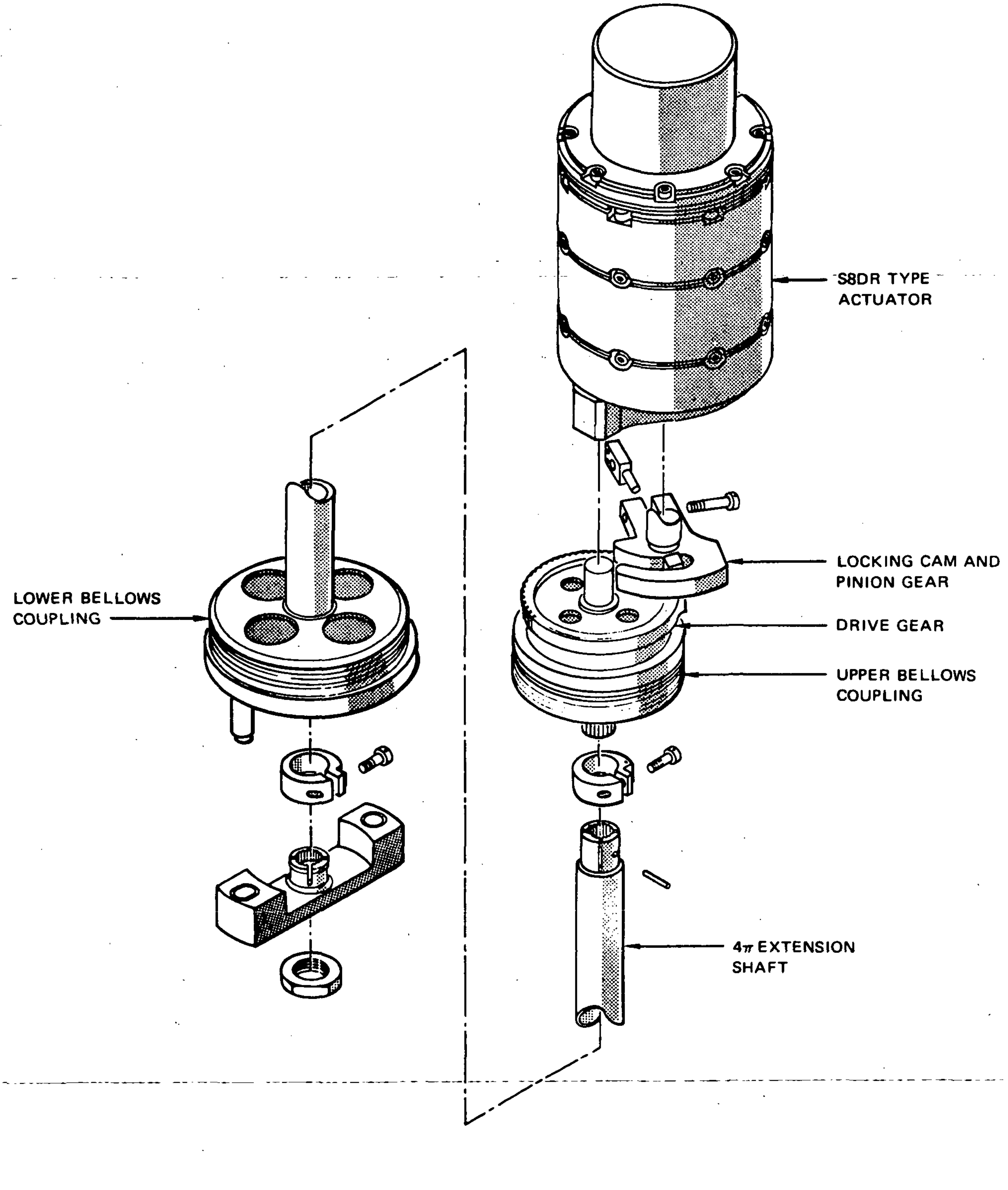


Figure 2-8. ZrH Reactor Control Drum Drive Train

2.5.3 REACTOR VESSEL

All parts of the containment vessel and associated structure supporting the core and control drums are Type 316 stainless steel. The NaK-78 coolant enters the lower vessel plenum at 860°K (1090°F) through four 38 mm (1.5 in.) inlet lines. The coolant flows upward in the area between the control-drum drywells, turns 180°, flows downward through the upper grid plate and the core, and exits from the core through the lower grid plate and then through the outlet plenum at approximately 945°K (1240°F). A minor amount of heat is transferred between inlet and outlet coolant through the flow-dividing cylinder; thus the NaK mixed-mean outlet temperature from the core is a few degrees hotter than the exiting temperature from the vessel.

To obtain optimum fuel-element lifetime, it is necessary to compensate for the core cosine radial power distribution by providing more coolant to the center of the core. This is accomplished by varying the spacing between fuel elements as a function of core radius. The spacing between elements ranges from 1.14 mm (0.045 in.) in the core center to about 0.25 mm (0.010 in.) at the edge. The irregular-shaped areas between the fuel-element array and the cylindrical core are filled with solid type 316 stainless steel or clad BeO filler pieces to prevent excessive coolant streaming. The inlet-to-outlet pressure drop of the reactor is 4.48×10^3 Newtons/m^2 (0.65 psi) under nominal flow rate conditions.

2.5.4 REACTOR SHIELD

Adjacent to the pressure vessel is a 4π gamma and neutron radiation shield which is arranged as shown in Figure 2-9. At the top of the reactor assembly the sum of the individual layers of tungsten and lithium hydride (LiH) approximates 0.085 m (3.35 in.) and 0.560 m (22.05 in.) respectively. The widest portion of the shield, however, is at the bottom where 0.160 m (6.3 in.) of tungsten and 0.790 m (31.1 in.) of lithium hydride are required. The exterior shield clad is stainless steel.

2.5.5 REACTOR NUCLEAR CHARACTERISTICS

The response of a reactor to accident situations is intimately related to its nuclear characteristics. These characteristics have not as yet been fully specified for the reference ZrH reactor. Reactor performance and control data assumed for this study are shown in Tables 2-4 and 2-5 (Reference 2-3).

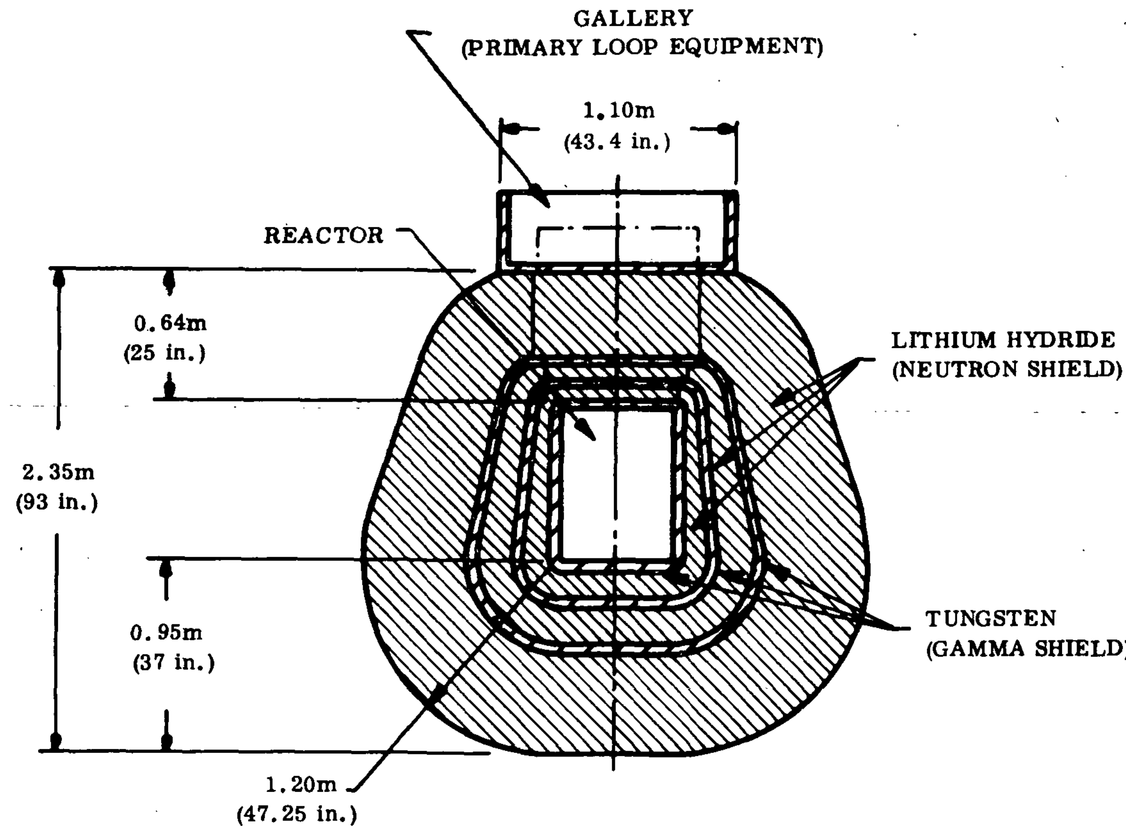


Figure 2-9. Reactor-Shield Combination

As nuclear operation proceeds, reactivity losses occur due to uranium burnup, fission product accumulation, and hydrogen loss from the fuel elements. A pre-poison (Gd-155) is used in the core to reduce the reactivity variation during the planned lifetime and reduce the control required by the control drums. The selected isotopes of the rare earth gadolinium in oxide form are applied by vapor deposition to the outer surface of the fuel rod to provide the necessary poisoning. The neutron absorption cross section (poison effectiveness) of the gadolinium is reduced through neutron capture during operation and provides the desired reactivity compensation. Reactivity and shutdown margins are important factors in reactor lifetime, control and safety of operation.

Table 2-5 shows that at the most reactive time in core life (after the period when pre-poison burnout overcompensates for reactivity losses) the reactor can be shut down with a comfortable margin even with one drum stuck in the most reactive position; yet enough reactivity can be added to maintain full-power operation if one drum sticks in the least reactive position.

Table 2-4. Typical Reactivity Summary
(330 kWt, 922°K (1200°F) Outlet, 5 yr)

Cold Clean Excess Reactivity Available		**$17.65**
$ 9, Gd-155/$ 3, Eu-151 Prepoison Loading	**-12.00**	
Cold Excess Reactivity at Launch		**5.65**
Temperature defect	**- 2.50**	
Power defect	**- 0.20**	
Xe-135 formation	**- 0.70**	
Core hydrogen redistribution	**- 0.25**	
Initial Operating Excess Reactivity		**2.00**
Hydrogen leakage	**- 2.40**	
Fuel burnup and fission-product accumulation	**- 6.79**	
Sm-149 formation	**- 1.03**	
Burnout of Gd-155/Eu-151	**+10.51**	
Excess Reactivity After 5 yr		**2.29**
Temperature defect	**+ 2.50**	
Power defect	**+ 0.20**	
Xe-135 decay	**+ 0.70**	
Hydrogen Redistribution	**+ 0.25**	
Cold Excess Reactivity at 5 yr		**5.94**

Note: Reactivity is a measure of the actual or potential neutron multiplication factor in a reactor; and therefore, the rate at which its power increases (or decreases). The reactivity of a reactor at steady state power (including zero power) is equal to zero. Not all neutrons emitted from fissioning fissile isotopes are emitted promptly at the instant of fission. Some are delayed, up to 55.6 seconds for U-235. Reactivity is expressed in multiple or fractions of dollars by the definition:

$$\text{REACTIVITY} = \frac{\text{Deviation of neutron multiplication from unity}}{\text{Fraction of neutrons which are emitted as delayed neutrons}}$$

$$\rho = \frac{k_{excess}}{\beta} \quad \text{(Dollars)}$$

For U-235, 0.75 percent of the total neutrons are emitted as delayed neutrons ($\beta = 0.0075$). Therefore, when the neutron multiplication factor is 1.0075, a deviation from unity of 0.0075, the reactivity, ρ, is equal to 0.0075/0.0075, unity. This condition is arbitrarily defined as a positive reactivity of one dollar, although more or less reactivity may be inserted by control drum rotation. Reactivity is always positive when power increases, and is always negative for power decreases.

Table 2-5. Reactivity Control Characteristics

	Drums Out*		Drums In*	
	All	1 Stuck-In	1 Stuck-Out	All
Reactivity Added by Control Drums	\$0	\$1.00	\$8.75	\$10.50
Shutdown Margin (Cold)				
Launch pad	-4.85	Not applicable		
Most reactive point in life	-2.76	-1.76		
5 yr	-4.56	-3.56		
Excess Reactivity (~~1200~~$^{\circ}$F; 600 kWt)				
Beginning-of-life			0.25	2.00
5 yr			0.54	2.29
Temperature Coefficients of Reactivity				
Fuel temperature	-0.10¢/$^{\circ}$F			
Coolant inlet temperature	-0.07¢/$^{\circ}$F			
Coolant outlet temperature	-0.03¢/$^{\circ}$F			

*The "out" position is least reactive (neutron absorber next to core).

Although reactivity loss is the ultimate life-limiting factor, two other associated life limits have been identified: (1) normal irradiation-induced growth of the fuel; and (2) hydrogen loss sufficient to cause phase transformation of the zirconium hydride. Transformation of the fuel from the Δ to β phase is known to result in accelerated fuel growth. Sufficient clearance is provided between the fuel and cladding to prevent contact due to normal irradiation growth during the reactor lifetime. The larger this clearance, however, the higher the fuel temperature which results in accelerated hydrogen loss and reduces the time to reach fuel-phase transformation. The fuel-to-cladding clearance is therefore optimized to maximize the reactor lifetime. Reactor lifetime operating at 330 kWt with an outlet temperature of 945°K (1240°F) is predicted to be greater than 5 years.

2.6 NaK-78 VOLUME/MASS

The volume and mass of the NaK in the EPS has been estimated and presented in Table 2-6.

Table 2-6. NaK Loop Volume and Mass

	Volume-m^3	Mass (kg)	(lbs)
Primary Loop			
Reactor	4.60×10^{-2}		
Intermediate Heat Exchanger	1.00×10^{-2}		
Piping & Pumps	2.60×10^{-2}		
	8.20×10^{-2}		
$\Delta V = 8.20 \times 10^{-2} \times 0.162 =$	1.30		
Subtotal	9.50×10^{-2} (5790 in.^{3})	66	(145)
Intermediate Loops			
Brayton Heater	0.80×10^{-2}		
Intermediate Heat Exchanger	0.70×10^{-2}		
Piping & Pumps	12.30×10^{-2}		
	13.80×10^{-2}		
$\Delta V = 13.80 \times 10^{-2} \times 0.162 =$	2.20		
Subtotal	16.00×10^{-2} (9750 in.^{3})	110	(240)
Heat Rejection Loops			
Radiator & Piping	9.20×10^{-2}		
$\Delta V = 9.20 \times 10^{-2} \times 0.0525 =$	0.50		
Subtotal	9.70×10^{-2} (5900 in.^{3})	68	(150)
Total	35.20×10^{-2} (21440 in.^{3})	244	(535)

2.7 REACTOR OPERATIONS

2.7.1 PRESTART CONDITIONS

The reference reactor and radiator would be housed within a moveable shroud prior to operation. The NaK-78 within the system freezes at approximately 250°K (10°F) and some small amount of heating and circulation of the liquid metal would be required. As the system comes up to power the shroud would be retracted and the radiator loops would come up to operating temperature.

2.7.2 STARTUP

Startup is initiated by activating the instrumentation and control circuits while making a systems status check to assure readiness. When system readiness has been received the startup command is given, auxiliary pumping is started, and control drum stepping is subsequently initiated. The sequence which follows is typically illustrated in Figure 2-10.

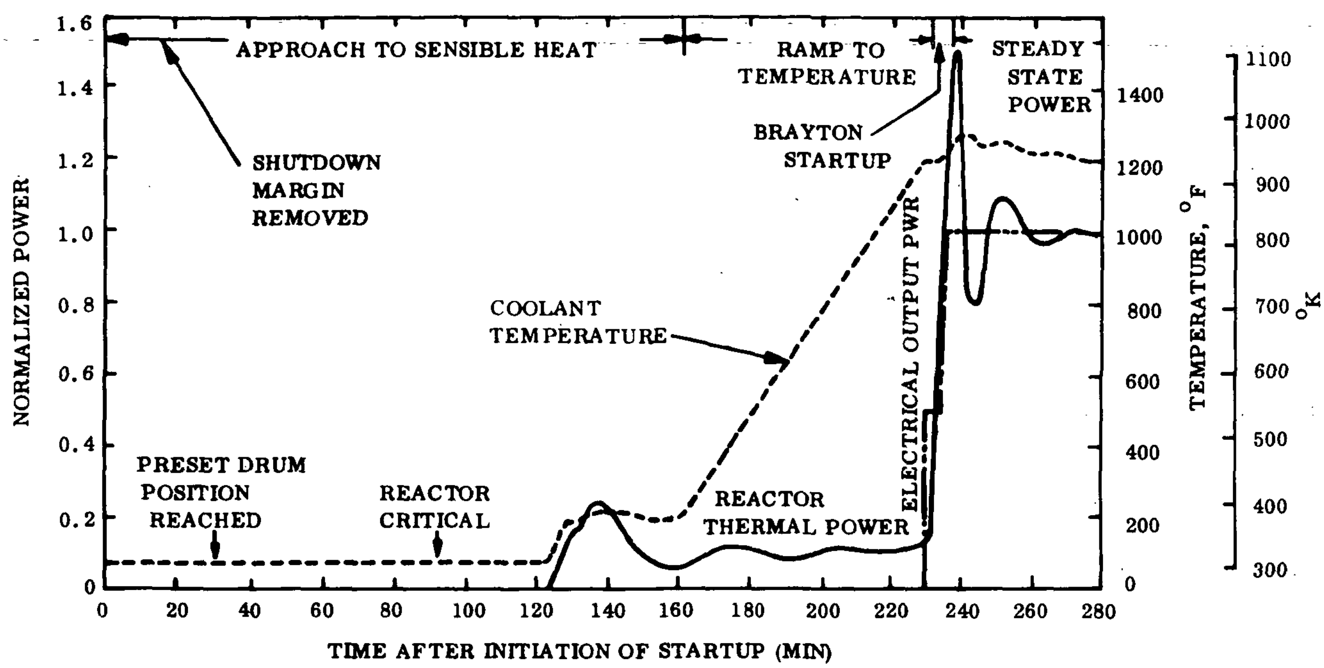


Figure 2-10. Typical Reactor Brayton Startup Transient

During the first phase of start-up, control drums are stepped in sequence at 3-sec intervals until they reach a preset drum position as indicated by the drum step counter. At this point the drum-stepping period is increased to 150 seconds. The reactor is subsequently made critical and undergoes a power-temperature transient. Pumping rates are increased at this point and the control drum stepping interval is reduced from 150 to 30 seconds. The reactor power is allowed to be quasi-stable at about 10 percent nominal power while the NaK and reactor temperatures increase. Drum stepping is continued until the reactor outlet temperatures reach approximately 945°K (1240°F), where the stepping is stopped and control is turned over to a fixed temperature program.

At this time, the Brayton unit can be started and brought up to speed. This is achieved by a simultaneous motor start and bearing feed gas injection. The Brayton unit can obtain self-sustaining operation with about 10 percent of the nominal gas pressure. After self-sustaining speed is achieved, the Brayton unit can be brought up to rated power at a preselected rate by increasing gas loop pressure. The condition shown in Figure 2-10 is considered a relatively rapid start-up sequence. In this instance no reactor control action was taken wherein actual operation reactivity would be removed when the reactor outlet temperature goes above the dead band, resulting in a less severe power transient.

2.7.3 REACTOR OPERATION

During steady state operation, the reactor and Brayton controls are nearly independent. The reactor control mechanism is initiated by reactor outlet temperature. Reactor temperature is controlled with a dead-band of $\pm 10^{\circ}K$. The separate control of the BRU is by a mixture of autonomous and remote control. The basic controlled variable is compressor discharge pressure which is adjusted by periodic pulsing of bleed and makeup valves stimulated by the dead-band controller.

The Brayton system is maintained at constant speed by means of an external parasitic load resistor, proper output voltage by means of alternator excitation control, and proper BRU loop power capacity by compressor discharge pressure control. Electrical output power can be changed by the addition or removal of gas from the Brayton loop. The reactor temperature controller then causes the reactor to adjust accordingly. Significant adjustments in electrical power require relatively small adjustments in reactor operation.

Sudden unplanned stoppage of a Brayton unit causes the temperature of the reactor to rise a few degrees and then return to normal. The coolant temperature difference approaches zero, resulting in an isothermal reactor. Malfunctions exist which can cause Brayton stoppage or dangerous overspeed conditions resulting in destruction of the unit. Failure of the parasitic load speed control would lead to dangerous overspeed. Alternator excitation failure also results in an overspeed condition. An overspeed trip is an essential safety feature to prevent this condition and allow feasible repairs to take place.

If a BRU failure occurs, ac power for NaK pump operation is provided from backup sources to permit decay heat removal. In many cases one of the standby BRU's would be started (a matter of minutes) to assume the load.

2.7.4 SHUTDOWN AND RESTART

The Brayton unit can be shut down by removing gas from the loop until the unit falls below self-sustaining speed. Supplemental bearing feed gas is required at speeds below 4,000 rpm. During this time the reactor can be maintained at a low power level at operating temperature or shut down. Normal shutdown of the reactor is accomplished by a reverse command which causes the control drums to step outward at the 3-second rate.

2.8 REFERENCES

2-1 "Space Base Concept Data - Space Base Subsystem Requirements," Volume III, MDC-G0576, McDonnell Douglas, June 1970.

2-2 "Reactor Power System Design Document - Appendices," Volume II, MDC-G0750, McDonnell Douglas, December 1970.

2-3 "Preliminary Reference Design Document - Reactor," Volume II, MDC-G0744, McDonnell Douglas, January 1971.

SECTION 3
REACTOR DISPOSAL SYSTEM

KEY CONTRIBUTORS

A. CARUVANA
J.A. GARATE

SECTION 3
REACTOR DISPOSAL SYSTEM

3.1 DESCRIPTION

A reactor disposal system is an integral part of the lower radiator structure of the reactor power module. The system was developed from a conceptual design study (Reference 3-1) conducted to identify key engineering elements involved in the synthesis of nuclear electric power system disposal techniques.

The Reactor Disposal System, shown in Figure 3-1, is divided into the following subsystems:

- Structural and Passive Temperature Control
- Separation
- Reaction Control System
- Main Propulsion
- Guidance and Control
- Electrical Power
- Tracking Transponder
- Telecommunications and On-Board Checkout

The structural system provides for the docking and release mechanism, umbilical connections, and related Space Base-Electrical Power System interfaces. A passive control system, consisting of multilayer superinsulation and small, strategically located heaters, is used to protect various system components from large temperature variations of $+158^{\circ}K$ to $+397^{\circ}K$ ($-175^{\circ}F$ to $+255^{\circ}F$).

Springs similar to those used on the APOLLO-LM program are used to separate the reactor power module from the Space Base and provide a ΔV of about 0.39 m/sec (1.13 ft/sec).

A cold gas Reaction Control System (RCS) is used for spin stabilization of the power module. The components within this subsystem include two pitch jets, two yaw jets and four roll jets.

The location of the RCS engines is shown in Figure 3-1. A schematic of the RCS is shown in Figure 3-2.

Four Thiokol 442-1 solid propellant motors are used for the primary propulsion system with a total ΔV capability of 254 m/sec (837 ft/sec). Each of the four rocket motors must perform properly in order to attain the desired final circular orbit. Failure of one or more of the rocket engines will leave the payload in either an elliptical or in a circular orbit at lower than the desired altitude.

The Guidance and Control (G&C) subsystem performs the following functions:

- Pre-checkout
- Attitude reference alignment
- Attitude stabilization following separation and thrusting
- Pitch and yaw attitude maneuvers
- Attitude hold
- Firing of main motors
- Attitude control during thrusting

Specific components within the subsystem include:

Gyros	Jet Logic
Horizon Sensors	Torquing/Heaters
Sun Sensor	Sensor Interfaces
Sequence/Timer	Power/Signal Conditioning

All of the electronics required for the G&C equipment are contained in the Command, Control and Sequences (CC&S) package. This package is hermetically sealed and pressured to protect its electrical circuitry from contamination. The major functions of the CC&S package is to:

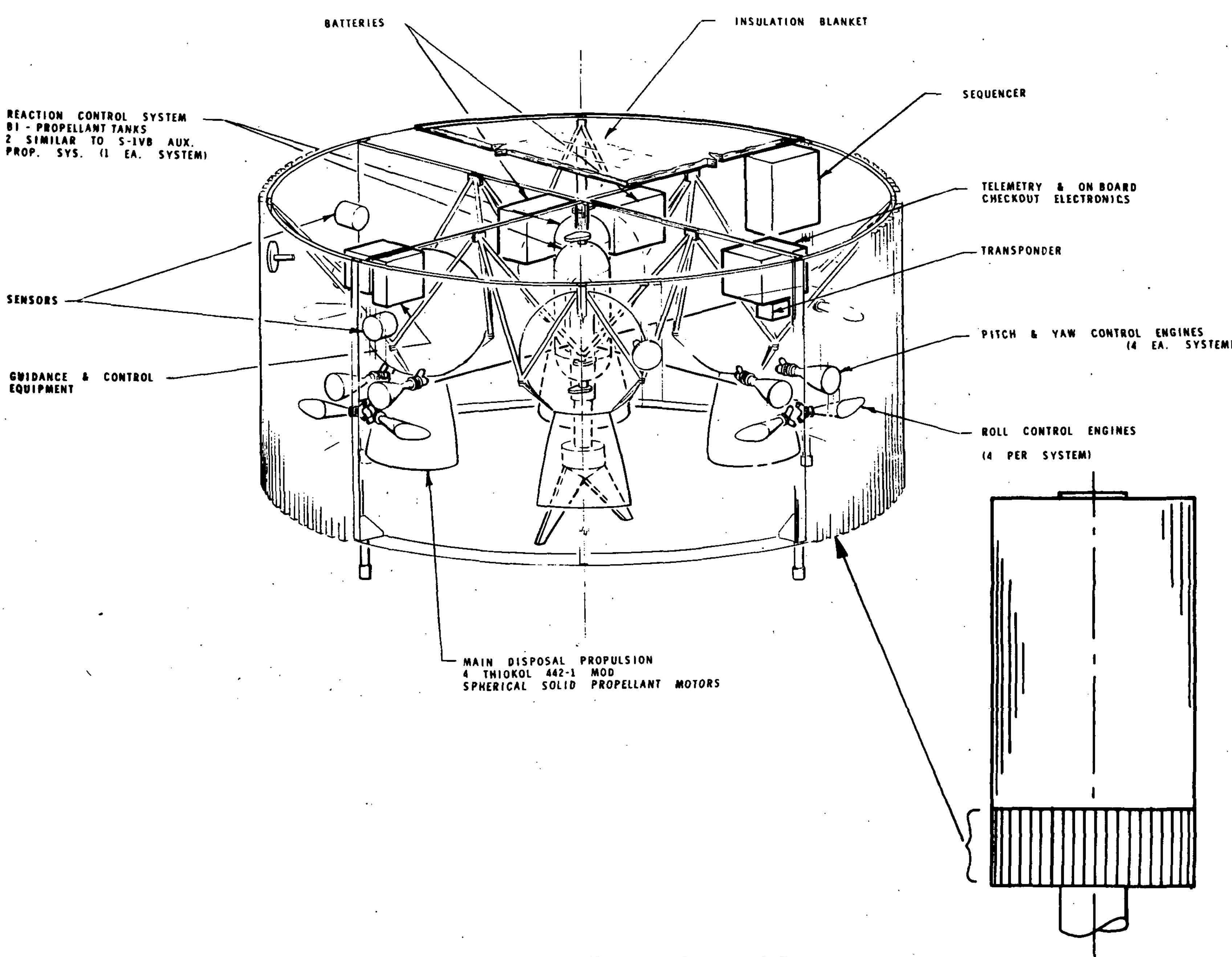


Figure 3-1. Reactor Disposal System

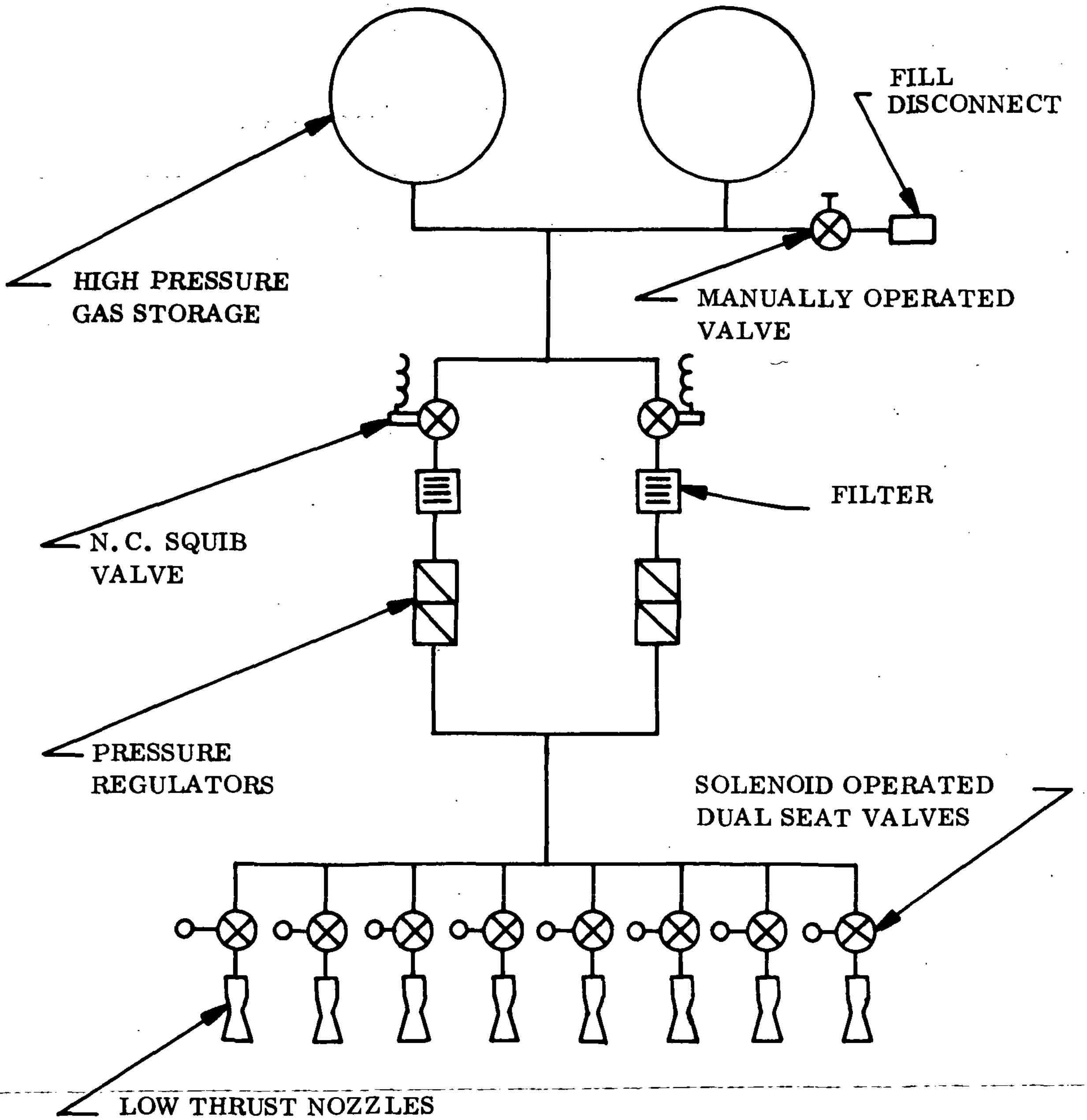


Figure 3-2. Stored Cold Gas Reaction Control System

- Provide sequence and logic
- Attitude control
- Power supplies
- Telemetry, checkout and alignment interfaces

It is assumed that initial disposal alignment can be provided by the Space Base; however, independent alignment by the Reactor Disposal System after separation from the Space Base is also considered a prime mode.

Two remotely activated silver-zinc batteries will supply electrical power for the Power Module (PM). Each battery has a capacity of approximately 1,200 watt-hours and is rated at 40 ampere-hours; the batteries are connected in parallel for supplying all PM subsystem electrical load requirements during disposal. Power diodes provide for electrical isolation of one battery from the other in the event that both batteries become connected to a common power distribution bus or to a common electrical load. This configuration and battery rating allows either battery to be used to supply the worst case power requirements shown in Figure 3-3.

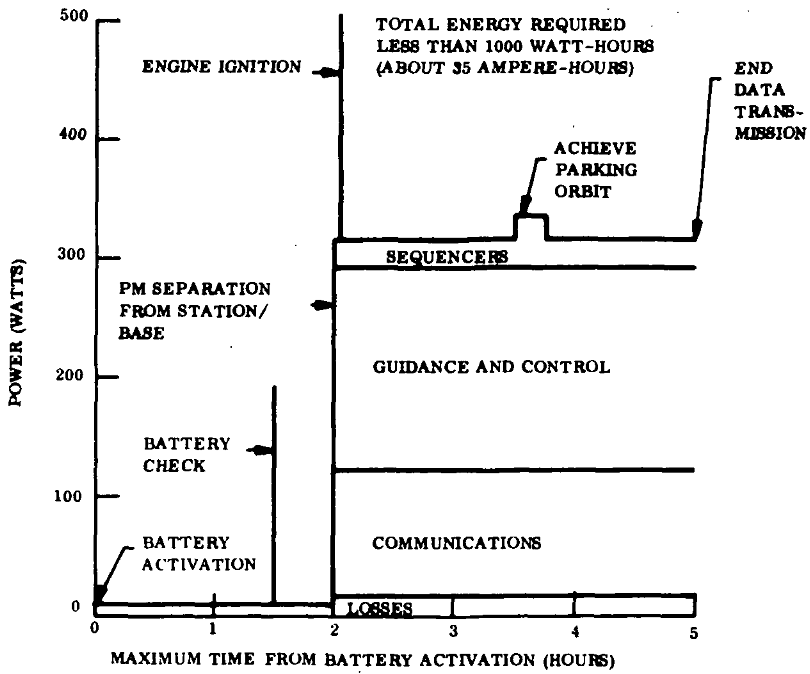


Figure 3-3. Power Profile for PM Disposal (Worst Case)

A transponder will be used to track the PM after it is released from the Space Base. The spent PM can be tracked during all disposal phases by the ground tracking network.

An on-board checkout system is incorporated into the Reactor Disposal System providing communication either with the Space Base or ground tracking stations via a telemetry system. The Reactor Disposal System can be checked out periodically by means of the on-board checkout system and the telemetry system. This will be accomplished by initiating an RF command signal from the Space Base to the PM and interrogating the PM. The return signal can be transmitted through a hardwired umbilical system. Interrogation by RF provides another means for total system checkout. Post separation communication with the PM can be performed by the Space Base and/or ground tracking stations via the telemetry system. Maximum battery time which will allow telemetry communications is five hours.

The on-board checkout system will provide signals to the receiver verifying a "go, no-go" status for each phase of disposal. The telemetry system combined with the on-board checkout system will provide necessary data to the controllers on which to base their decisions to continue or discontinue the next phase of the disposal operation.

3.2 REFERENCES

3-1 "Post Operational Safety of Reactor Power System for NASA Space Station," Volume V, AI-AEC-MEMO-12917; Atomics International, North American Rockwell, June 1970.

SECTION 4
SPACE BASE

KEY CONTRIBUTOR

E.E. GERRELS

SECTION 4
SPACE BASE

A baseline Space Base configuration was established from recent studies performed for NASA by North American Rockwell and McDonnell Douglas (Reference 4-1 and 4-2). The baseline provides a reference design against which results of the study can be compared and evaluated in the future.

The Space Base consists of: (1) the zero-g core modules; (2) a series of artificial-g modules attached at a 30 m (approximately 100 ft) radius from a rotating hub; (3) detached and attached experiment modules; (4) two ZrH Brayton cycle reactor power modules suspended on booms some 60 m (200 ft) from the basic core modules. An artist concept of the reference Space Base is shown in Figure 4-1.

Basic elements of the design are common modules 10 m (33 ft) in diameter which make up the main living and work areas. When built up by a series of Saturn and Space Shuttle launches, capability of supporting a 50-man crew for a 10-year mission exists. Projected lifetime of the reactor power modules is 5 years. Therefore, reactor Power Module (PM) repair, replacement and disposal are required during and at the end of the mission.

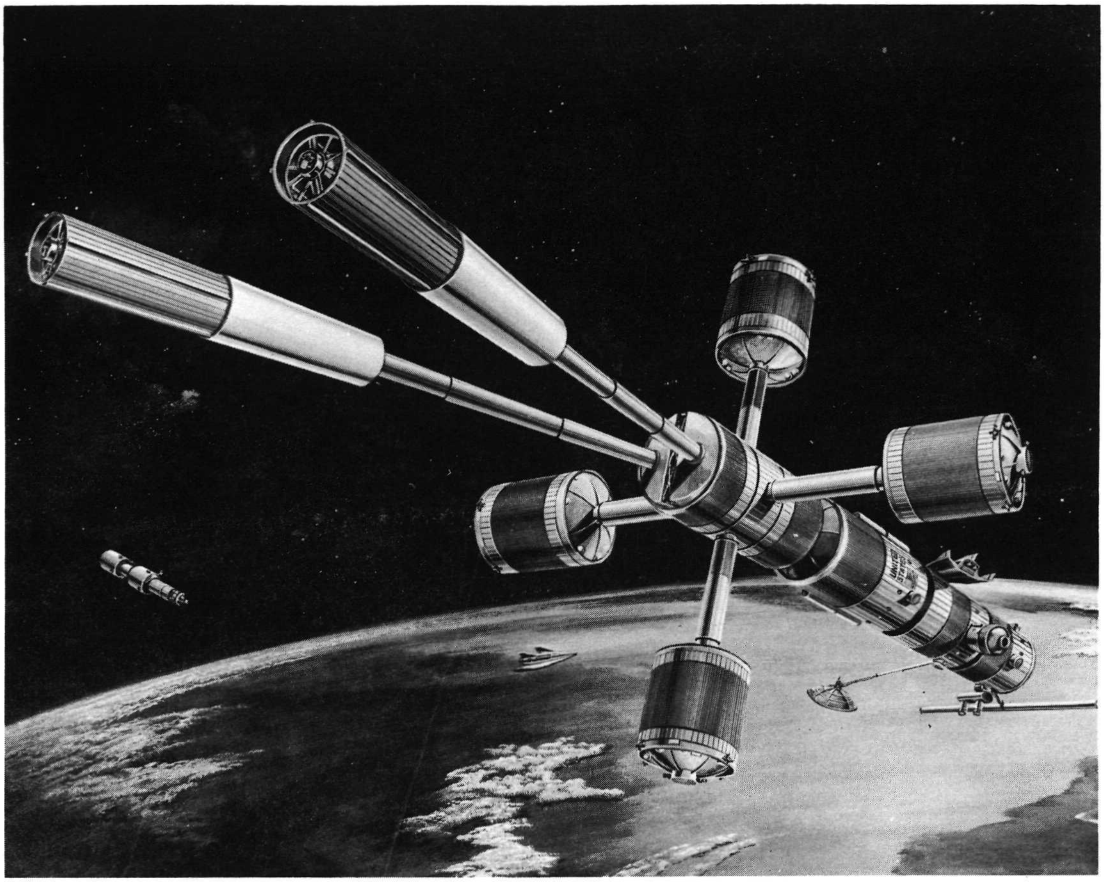
The primary logistic and operational support vehicles are the Space Shuttle and Space Tug. Docking of the PM units to the Base is assumed to be accomplished with the Space Tug.

During normal operations the two reactor PM units will provide a maximum of 100 kWe conditioned power. It is assumed that a single PM could provide the total load for short periods during shutdown or failure of the other PM. Backup power of approximately 16 kWe is provided by a solar array.

REFERENCES

4-1. "Space Base Concept Data," Volume I-VIII, MDC-G0576, McDonnell Douglas, June 1970.

4-2. "Space Base Definition," Volume I-III, MSC-00721 (SD70-160), North American Rockwell, July 1970.



LAUNCH TECHNIQUE	INT-21, KICKSTAGE AND SHUTTLE
ORBIT PARAMETERS	500 km (273 nm) 55° - 30° INCL.
ATTITUDE IN ORBIT	MULTI-ORIENTATION
VEHICLE CONFIGURATION	10 m (33 ft) DIAMETER MODULES
MISSION LIFE	10 YEARS IN EARTH ORBIT
EXPERIMENTS	VARIOUS ON-BOARD AND FREE FLYING
POWER SYSTEM	2-ZrH REACTOR BRAYTON POWER MODULES & SOLAR ARRAY

Figure 4-1. Reference Space Base

SECTION 5
LAUNCH VEHICLE

KEY CONTRIBUTOR

J.A. GARATE

SECTION 5
LAUNCH VEHICLE

The baseline vehicle employed to launch the reactor power modules is the INT-21, which is a Saturn V derivative using the existing S-IC and S-II stages. Figure 5-1 shows the baseline vehicle outline and payload shape. The salient characteristics of the S-IC and S-II stages are shown in Figure 5-2.

5.1 S-IC STAGE

The S-IC stage is a cylindrical booster, 42 m (138 ft) long and 10 m (33 ft) in diameter, powered by five liquid propellant F-1 rocket engines using LOX/RF as propellants. These engines develop a nominal sea level thrust of 3.42×10^7 newtons (7,610 klb) total, and have a maximum burn time of 168.0 seconds.

The S-IC stage provides first stage boost of the INT-21 launch vehicle to an attitude of about 60 km (approximately 200 kft), and provides acceleration to increase the vehicle inertial velocity to 2752 m/sec (9,029 ft/sec). It then separates from the S-II stage and falls to earth about 665 km (360 nm) downrange.

The S-IC first stage is of double tank aluminum skin-stringer-frame construction. The 2219-T87 tanks are joined by a 7075-T6 A1 corrugated, ring-stiffened interstage. The forward and aft skirt are 7075-T6 A1 skin cylinders with stringer and ring frame stiffening. The heavier LOX is placed forward of the lighter RF (RP-1) for smaller control moment requirements. Four fins are used for increased abort stability and are mounted on the outboard engine fairing as are eight retro rockets for staging.

5.2 S-II STAGE

The S-II stage provides second stage boost for the INT-21 launch vehicle. The stage is 24.8 m (81.5 ft) long, 10 m (33 ft) in diameter, and is powered by five liquid propellant J-2 rocket engines which together develop a nominal vacuum thrust of 5.1×10^6 newtons

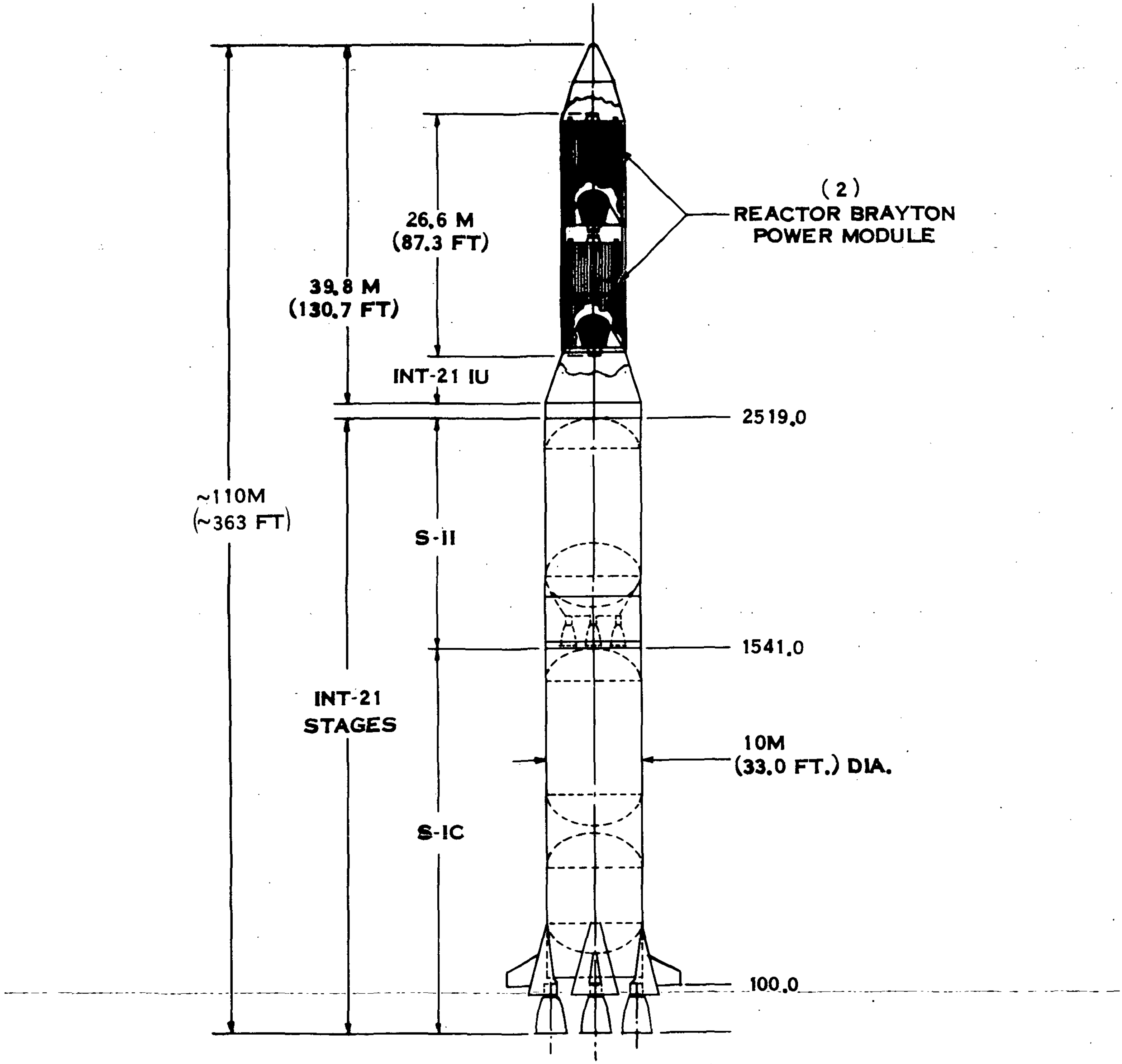
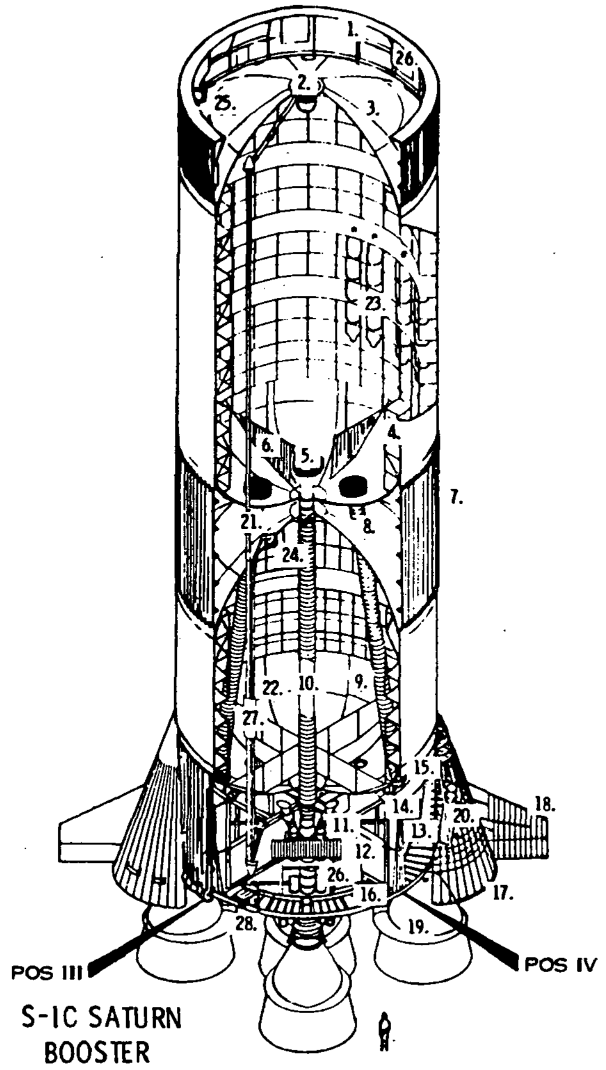


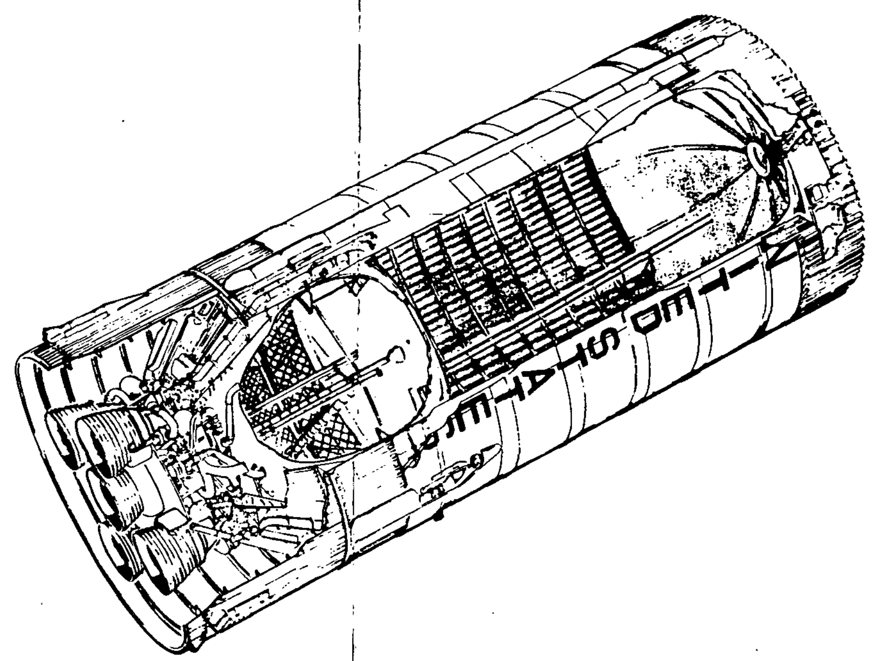
Figure 5-1. INT-21 Launch Vehicle and Payload Configuration

MAJOR COMPONENTS
1. FORWARD SKIRT STRUCTURE
2. GOX DISTRIBUTOR
3. LOX TANK
4. ANTI-SLOSH BAFFLES
5. ANTI-VORTEX DEVICE
6. CRUCIFORM BAFFLE
7. INTERTANK STRUCTURE
8. FUEL TANK
9. SUCTION LINE TUNNELS
10. LOX SUCTION DUCTS
11. FUEL SUCTION DUCTS
12. CENTER ENGINE SUPPORT
13. THRUST COLUMN
14. HOLD DOWN POST
15. UPPER THRUST RING
16. LOWER THRUST RING
17. ENGINE FAIRING
18. FIN
19. F-1 ENGINE
20. RETRO ROCKETS
21. GOX DUCT
22. HELIUM DUCT
23. HELIUM CONTAINER
24. HELIUM DISTRIBUTOR
25. LOX VENT DUCT
26. INSTRUMENTATION PANELS
27. CABLE TUNNEL
28. UMBILICAL PANEL



S-IC Characteristics

Length-m	42.1	(138 ft)
Diameter-m	10.0	(33 ft)
Dry mass-t	135.4	(298.6 klb)m
Liftoff mass-t	2,825.3	(6,229.7 klb)m
T/W ratio	1.222	
Sea level thrust - Newtons	3.42×10^7	(7,610 klb)f
Sea level Isp-sec	264.5	
Propellant consumed-t	2,075.8	(4,577 klb)m
Mass at staging-t	168.1	(370 klbs)m
Maximum acceleration-g	4,535	
Maximum dynamic pressure-Newton/m^2	31,848	(665 lb/ft^2)
Flight azimuth-deg	46	
Main Propulsion Engines	5-F1	
Propellants	LOX & RF	
Mainstage Capacity-t (RF)	642	(1,416 klbs)m
(LOX)	1,442	(3,179 klbs)m
Separation System	Solid	



S-II Characteristics

Length-m	24.8	(81.5 ft)
Diameter-m	10.0	(33 ft)
Dry mass-t	38.3	(84.5 klb)m
Liftoff mass-t	581.3	(1,281.8 klbs)m
Thrust (VAC)-Newtons	5.1×10^6	(1,150 klbs)f
Isp (VAC)	429.2 max.	
Propellant consumed-t	437.7	(965.2 klbs)m
Mass at staging-t	43.2	(95.2 klbs)m
Main Propulsion Engines	5-J2	
Propellants	LH_2 & LOX	
Mainstage Capacity-t (LH_2)	71.6	(158 klbs)m
(LOX)	371.4	(819 klbs)m
Avionics-t	3.6	(8 klbs)m
Payload inserted t	86.2	(190 klbs)m
Separation System	Solid	

Figure 5-2. S-IC and S-II Stages Characteristic Summary

(1,150 klb). The four outer J-2 engines, equally spaced on a 5.33 m (17.5 ft) diameter circle, are capable of being gimbaled through a plus or minus 7.0 degree pattern for thrust vector control. The fifth engine is mounted on the stage centerline and is fixed.

At engine cutoff the S-II stage separates from the power module and, following a suborbital path, reenters, the atmosphere where it disintegrates due to reentry loads. The S-II second stage is a combined tank with a 2014 A1 and fiberglass phenolic honeycomb common bulkhead between the LOX and LH_2 tanks. The tanks are 2014 A1 alloy, integrally-stiffened skin cylinders with ellipsoidal bulkheads. The forward and aft skirts are 7075 A1 alloy skin-stringer-frame construction.

5.3 INSTRUMENT UNIT

The launch vehicle is guided from its launch pad into earth orbit by navigation, guidance and control equipment located in the Instrument Unit (IU). The IU is a cylindrical structure located between the S-II stage and the power module. An all-inertial system, using a space stabilized platform for acceleration and attitude measurements, is utilized. A Launch Vehicle Digital Computer (LVDC) is used to solve guidance equations and a flight control computer (analog) is used for the flight control functions. In addition, the IU contains telemetry and tracking systems.

SECTION 6

LAUNCH AND MISSION SUPPORT FACILITIES AND EQUIPMENT

KEY CONTRIBUTORS

J.A. GARATE
E.E. GERRELS

SECTION 6
LAUNCH AND MISSION SUPPORT FACILITIES AND EQUIPMENT

The principle reference launch and mission support facilities for the Space Base and its reactor power modules are the John F. Kennedy Space Center (KSC), Range Safety, Ground Tracking Networks, Recovery Forces and the Mission Control at MSC. An overall view of the launch area at KSC and surrounding facilities is shown in Figure 6-1.

As in the present Apollo program, the center of activity is Launch Complex 39 (Figure 6-2). The major facilities at KSC and tentative additions required to accommodate the Space Base power module launches include:

Existing (some modifications required)

- Vehicle Assembly Building (VAB)
- Mobile Launcher (ML)
- Crawler
- Launch Control Center (LCC)
- Launch Pad A and B
- Mobile Services Structure (MSS)
- Ordnance Storage Facility

Additions

- Nuclear Assembly Building (NAB)
- Liquid Metal Facility
- Transporter & Specialized GSE

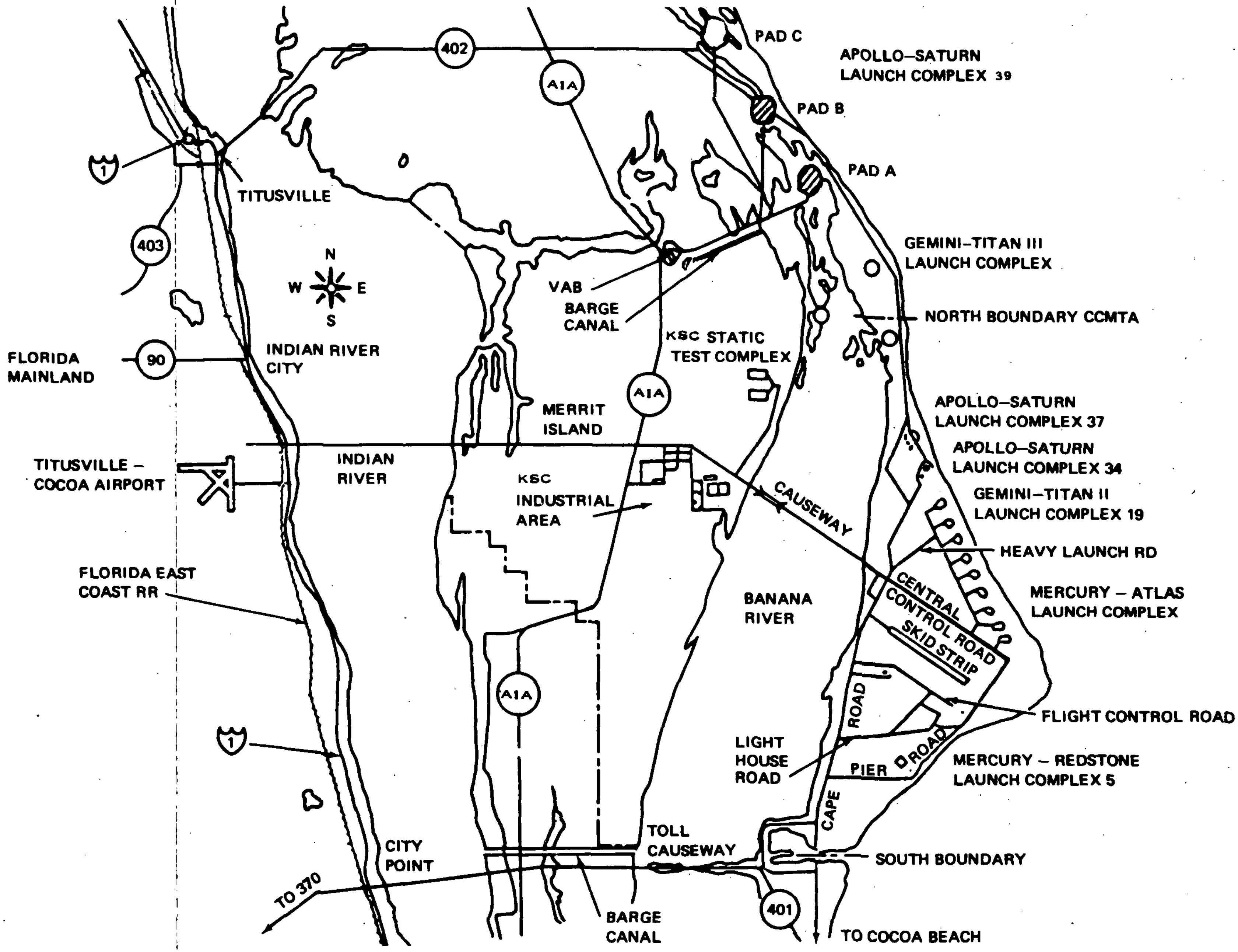


Figure 6-1. John F. Kennedy Space Center

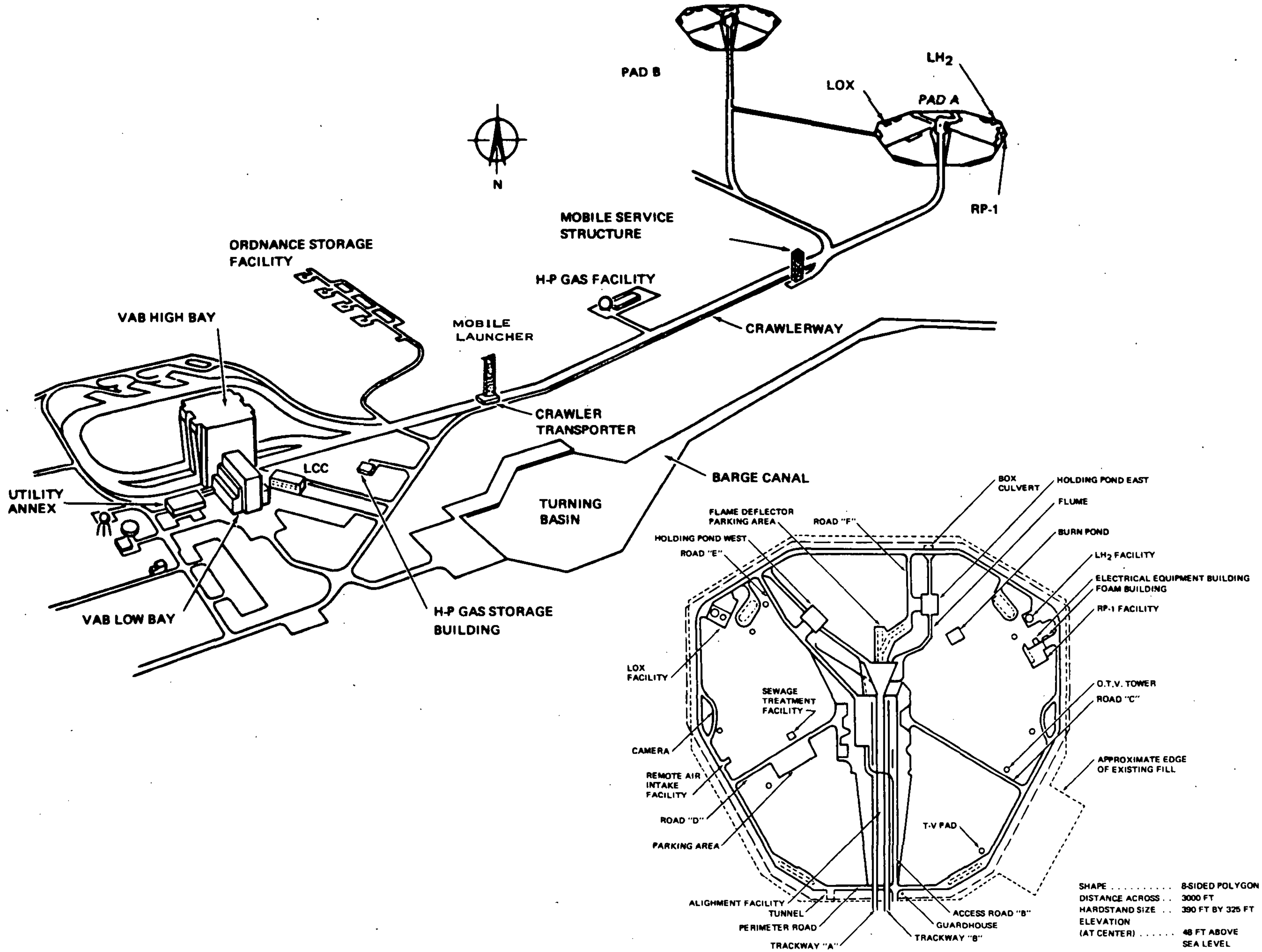


Figure 6-2. Launch Complex 39

6.1 EXISTING FACILITIES

For the most part, the support of the reactor Power Module (PM) can be accomplished by planned modifications to existing facilities. Liquid metal fire fighting provisions must be accommodated at the VAB, ML and Pad areas. The increased diameter of the PM payload over the S-IV B will require modifications to the service arms and work platforms of the ML, VAB and MSS. In addition, a protective cover gas capability is required at the payload level of the ML to provide an inert atmosphere around hardware containing liquid metal. Provisions will also be required for the addition of power module GSE in the ML, VAB, and in the LCC. Other than the requirement for liquid metal fire suppression, the basic launch pad should remain relatively unchanged.

6.2 ADDITIONAL FACILITIES

6.2.1 NUCLEAR ASSEMBLY BUILDING (NAB)

A new facility or modification to an existing isolated facility is required for the receiving inspection, storage, checkout and assembly of the reactor PM units. This facility must be capable of servicing and storing at least 3 PM units within a controlled access and controlled environment in accordance with AEC, and NASA-KSC requirements.

6.2.2 LIQUID METAL FACILITY

The reactor PM units will be delivered to KSC completely loaded with NaK-78. Under normal operating conditions NaK lines would not be opened. However, provisions must be available for the safing of a system which has developed a leak either upon arrival at KSC or during prelaunch operations. A minimum liquid metal handling facility is required which is capable of unloading NaK from the system prior to shipment back to the factory.

6.2.3 POWER MODULE TRANSPORTER

A PM transporter trailer will be provided for use from the point of assembly to the final integration with the launch vehicle at KSC. This vehicle will: (1) provide environmental and shock protection; (2) serve as the transport trailer in the aircraft or barge and at KSC; (3) be capable for use as a storage facility. The transporter will include provisions for supplying the cover gas, humidity control, fire fighting and status and radiation monitoring equipment.

6.3 RANGE SAFETY

The INT-21 launch vehicle will have destruct systems on both the S-IC and S-II stages. The S-II destruct system will be considered to be safed before Eurasian land mass overfly in order to take advantage of any possible range extension. Before destruct command, a signal will be sent for engine cut-off which then arms the destruct system. Several data points are used in reaching a decision to destruct such as: (1) the vehicle reaching a pre-established limit line which is a function of the boost vehicle and payload; (2) vehicle loss of altitude, or (3) vehicle loss of control. Reaction times for a range officer to initiate the destruct command are up to 20 seconds. The desirability of pre-separation of the PM prior to destruct is questionable, due to the large ΔV required to provide adequate separation distance within the time provided for destruct. No credible jettison capability is assumed for the reference vehicle and payload.

6.4 TRACKING AND DATA NETWORK

The communications and tracking network assumed for the reference vehicle, Space Base and PM includes the Launch Control Center, Mission Control Center, Data Relay Satellite System, and the telemetry and tracking capability of the Manned Space Flight Network.

Principal control through S-II cutoff and initial orbit insertion will be the responsibility of NASA-KSC and its tracking stations. After orbit attainment control will rest with the Mission Control Center (MCC) and the Space Base. It is assumed telemetry/status monitoring and command control of the PM can be provided by both the Space Base and the MCC.

Space Base tracking and telemetry will be used to perform the reactor disposal operation. The MCC will provide backup capability. The PM is tracked to a safe distance behind the base, and after confirmation of stabilization and orientation, the command is given for thrusting of the disposal rockets for placement into a transfer orbit. The PM is continually tracked until the second command is given for final orbit circularization.

Tracking aid equipment and a transponder is placed on the PM to assist long range tracking and computation of final orbit.

The present Manned Space Flight Network is not entirely adequate for the 55° inclination orbit and the potential impact areas associated with the vehicles. The use of other facilities and deployment of tracking ships could provide the supplementary tracking data required.

SECTION 7
BASELINE MISSION

<u>KEY CONTRIBUTORS</u>

J.A. GARATE
E.E. GERRELS

SECTION 7
BASELINE MISSION

The reference mission used in this safety study is presented in this section and is briefly summarized below.

The reactor power modules will be launched from Complex 39 at the John F. Kennedy Space Center. The INT-21 launch vehicle will boost the power modules to rendezvous with the awaiting orbiting Space Base. Space tugs will withdraw the reactor power modules from the payload shroud, and dock them to the Space Base. After a brief checkout period, the power modules will be brought to full power (330 kWt) and operated continuously for five years. At this point, when the operational lifetime of the reactor is completed, each reactor will be shut down, separated from the Base, and placed in a 990 kilometer (535 nautical mile) circular orbit to allow decay of the fission product inventory. The mission phases for the Electrical Power System are shown in Figure 7-1 and are discussed in detail in the following sections.

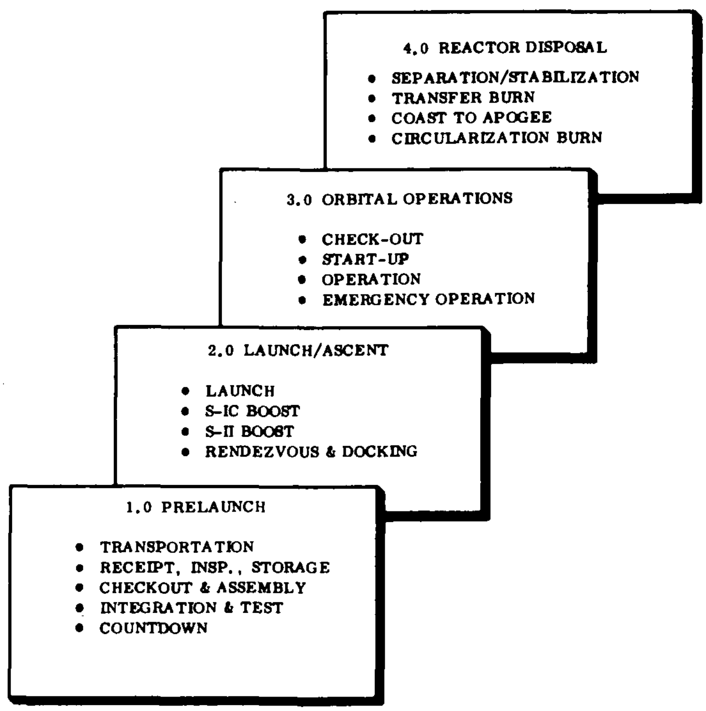


Figure 7-1. Mission Phases (Reactor Power Module)

7.1 MISSION SEQUENCE

7.1.1 PHASE 1.0 PRELAUNCH

The Prelaunch Phase is assumed to contain the following activities: (1) Transportation; (2) Receipt, Inspection and Storage; (3) Prelaunch Checkout and Assembly; (4) Launch Vehicle/Payload Integration and Test; (5) Launch Complex/Range Integration and Test; and, (6) Countdown.

7.1.1.1 Transportation

The transportation description of the Reactor Power Module (PM) at KSC is based on the assumption that the PM will be shipped to KSC in a nearly completely assembled configuration. All NaK loops will be filled before the final acceptance testing at the factory and will remain filled throughout all subsequent operations. Separable sections of the radiator and shield are only permitted if liquid metal lines are not broken. The PM would arrive in an environmentally controlled shipping container which provides the proper monitoring equipment and ensures a clean, dry atmosphere. Previous operation of the reactor was limited to near zero power critical tests, therefore radiation levels around the reactor would be very low.

The PM will be taken from the arriving airplane (or barge) by land transport to the Receipt and Inspection area (Nuclear Assembly Building) which is presently an undefined facility at KSC.

Three reactor PM units will be delivered, the third PM serving as the backup. Subsequent PM units will be delivered to KSC to serve as replacements during the mission. The first PM will be delivered approximately 90 days prior to launch, the second - 60 days, the third - 45 days. Transportation at KSC will be by truck/transporter trailer between the port of arrival, and Nuclear Assembly Building(NAB), the VAB and/or Complex 39.

7.1.1.2 Receipt, Inspection and Storage

The transporter and PM will receive a comprehensive receiving inspection for proper configuration, visual damage and monitoring of instruments designed to record shock loads, environmental conditions such as humidity, air chemical composition and radiation. The transporter will be opened and an inspection made of the PM for visual damage, fluid leaks, system integrity and electrical harness and umbilical connections. Provision is made for the discharging and purging of the liquid metal systems such that if a leak were detected, the system could be safed for shipment back to the factory. Reactor control safety devices will be checked. Consideration is given to the use of the transporter during all phases of inspection, checkout and storage providing a universal piece of hardware equipped with proper status and safety instrumentation.

Storage of three PM units is to be provided with maximum storage times of at least one year. In addition to the two PM units on the Space Base in orbit, a minimum of two replacement PM units are stored in a ready condition during the operational mission. Routine airborne and surface radiation and contamination measurements are made while the hardware is in storage. Periodic (180 days) power module verification checks are also made. Preparation for storage will involve enclosing the entire PM within the transporter under a protective cover of dry gas (argon or N_2). Purging of the container is required whenever the enclosure is opened. Therefore, status monitoring provisions will be made through the container walls to enable periodic checkout without opening the enclosure.

7.1.1.3 Prelaunch Checkout

Prior to integration with the booster or placement in storage, a series of subsystem verification tests will be performed to assure the integrity and functional operation of the PM. The nuclear facility utilized for storage would also serve as the checkout and assembly area. Consideration is given to the performance of tests on the transporter in conjunction with a series of semi-portable test equipment. Continuity tests will be given electrical connections and harnesses. Pressure and leak tests will be made and the PM coolant system will be operated to verify functioning of the PCS, valves, TEM pumps, and liquid lines. Minimum loop flow tests will be made which will require the use of strip heaters to provide sufficient thermal energy for operation of the NaK pumps.

Individual reactor control drums will be checked to verify operation and response characteristics and safing devices checked and installed. No criticality test is made. A PM systems test will then be performed where booster and spacecraft interface electrical signals can be sent, received and sequenced for prelaunch and in-flight simulation. Mechanical and electrical interfaces will be checked to ensure compatibility with the launch vehicles and spacecraft. Booster interface rings and shrouds are used to check for mechanical interface conformance. As in the case of all subsequent tests, nuclear safety regulations are to be followed. Materials and personnel within the prescribed test areas must be controlled. Actual testing within the facility will comprise a minimum of ten days. After prelaunch tests the PM will be prepared for transportation to the VAB or Mobile Launcher (ML) for integration with the launch vehicle or put in interim storage. This operation includes the addition of the module radiator shrouds and the installation of special instrumentation safing and ordnance devices.

7.1.1.4 Launch Vehicle and Payload Integration and Test

The nature of the launch vehicle integration tests to be performed are dependent on the selection of the launch vehicle and facility safety constraints. The reference baseline launch vehicle is the INT-21. The possibilities exist of integrating the power module within the VAB or performing all integration tests at the Launch Pad Complex 39. In either case, the PM should be scheduled as late in the sequence as possible. For purposes of the safety analysis, integration of the PM units within the VAB is assumed. Launch vehicle integration involves the mating of the hardware and the performance of those interface and combined systems tests to assure launch readiness. Countdown demonstrations are performed and certain post-launch conditions are simulated such as PM separation, umbilical disconnect and instrumentation and power transfers.

Initial mating/loading checks with the booster and the handling devices will be performed utilizing a dummy payload. Electrical and mechanical interfaces are simulated. A simulated systems launch readiness and countdown test is performed in this configuration to insure compatibility of instrumentation, environmental and support systems. A continuous and comprehensive systems status check and flight readiness test is performed prior to the ignition sequences and liftoff. For purposes of the safety study, it is assumed that either a single or a dual reactor launch can be performed.

7.1.1.5 Launch Complex/Range Integration and Test

At approximately T-8 days the Space Vehicle complete with Reactor PM(s) is delivered to Launch Complex 39 via the Mobile Launch Crawler. The shroud is maintained in position around the PM at all times. PM instrumentation monitored includes umbilical and separation circuit connections, radioactivity, environmental conditions and control circuit continuity. Telemetry radio frequency interference and range verification tests are made. Simulated countdown, propellant loading, and pressure tests are made.

7.1.1.6 Countdown

The countdown is initiated on the INT-21 at T-2 days where flight readiness and functional checks are given major subsystems. Special cryogenic and spacecraft fuel tanks are loaded. Ordnance (including disposal rockets) are installed (T-15 to T-10 hours) prior to launch vehicle cryogenic loading. Pad accessibility is very much limited at this point. Continuous monitoring of systems is provided throughout the final phases of the countdown. The terminal countdown is initiated at T-1 hour with the completion of all flight readiness checks and the propellant loading sequences. An automatic sequence for the start of the engines is initiated at T-187 seconds. Swing arms are around the vehicles until the automatic sequence is initiated, however, the removal of some upper service arms would be permissible at an earlier hour to afford abort potential. This phase terminates with ignition of the S-IC booster engines.

7.1.2 PHASE 2.0 LAUNCH AND ASCENT

The INT-21 launch vehicle will be used to boost the reactor PM(s) to orbit from Launch Complex 39. Two reactor power modules can be launched by one INT-21 booster. A detailed description of the vehicle and complex facilities is presented in Sections 5 and 6.

The reactors are dormant during the launch and ascent phases. However, a small amount of power may be supplied from a temporary source to provide a minimum flow of NaK in the primary, intermediate and heat rejection loops. This flow prevents localized freezing of the NaK during ascent and prior to reactor startup.

The Space Base Mission requires insertion of the payload into a 500 km (273 nm) circular orbit inclined 55 degrees to the earth equatorial plane. The launch azimuth for this orbit is 46 degrees, measured east of north, as a result of current range safety requirements at the Eastern Test Range (ETR). This azimuth is not compatible with the desired orbit inclination; therefore, a plane change of 6-degrees (S-II stage yaw) is employed when the impact points pass Newfoundland, providng a new azimuth of $\sim 40^{\circ}$.

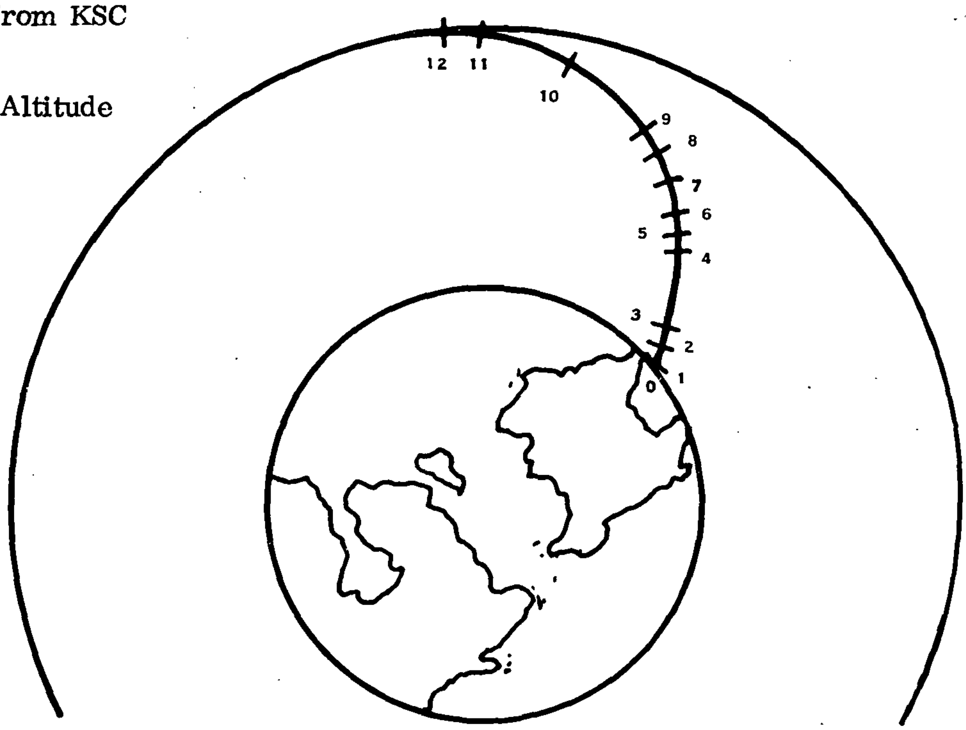
The INT-21 flight sequence is shown in Table 7-1 (Reference 7-1 and 7-2). At first motion the launch vehicle begins a rise of 138 meters to clear the launch umbilical tower. Following tower clearance a pitch program induces a turning rate on the launch vehicle. The pitch program continues until 41 seconds after first motion. At this time the launch vehicle begins a gravity-tilt profile which continues until tilt arrest at 153 seconds after first motion. Tilt arrest is maintained during S-IC/S-II staging and continues through the remainder of the atmospheric portion of flight.

The payload enclosure (shroud) is jettisoned 195 seconds after first motion. Atmospheric flight is terminated approximately four seconds later. Vacuum flight and the Iterative Guidance Mode (IGM) are initiated at 199 seconds with the IGM providing both pitch and yaw steering commands during the remainder of the ascent to orbit.

Table 7-1. Sequence of Events for Typical INT-21 Launch from KSC

55^{o} Inclination

456 Kilometer Altitude



Seq. No.	Event	Time (Sec)	
		Max Payload	86t Payload
0	Ignition	-9	-9
1	Lift-Off	0	0
2	Initiate Tiltover	11	12
3	End Tiltover-Begin Gravity Turn	41	35
4	S-IC Center-Engine Cutoff (CECO)	139	149
5	S-IC Burnout	157	161
6	S-IC-SII Separation	159	163
7	S-II Ignition	161	165
8	Interstage Jettison	189	
9	Shroud Jettison	195	193
10	S-II-CECO	458	
11	Guidance Cutoff	547	
12	Orbit Insertion	557	544

Time histories of inertial velocity, altitude, and inertial flight-path angle during the boost to orbit are presented in Figures 7-2 through 7-4. A summary of critical flight parameters is given in Table 7-2.

It is assumed that the launch vehicle propulsion module, which contains the IU, incorporates features which allow rendezvous with the orbiting Space Base. It is also assumed that a "Space Tug" will withdraw the reactor PM from the payload shroud, and perform docking operations with the Base. Maximum closing velocities are not to exceed about 1.5 m/sec (5 ft/sec).

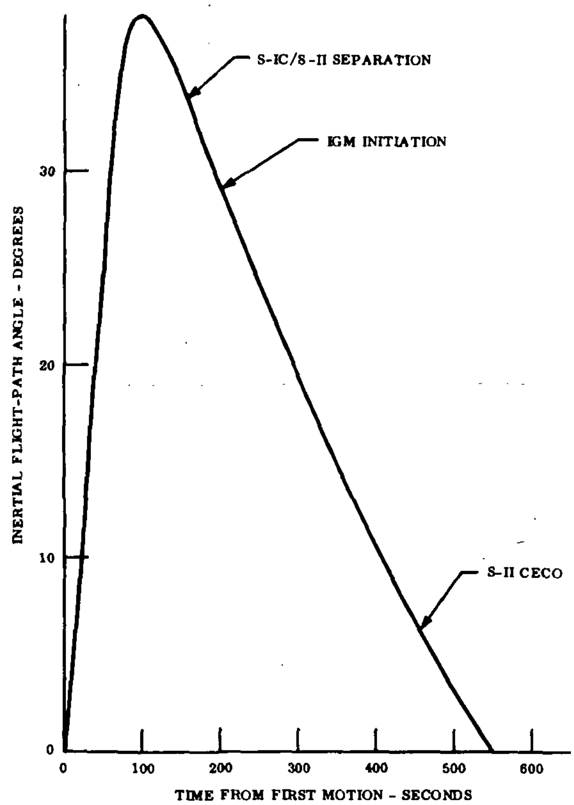


Figure 7-3. Altitude History During Boost to Orbit

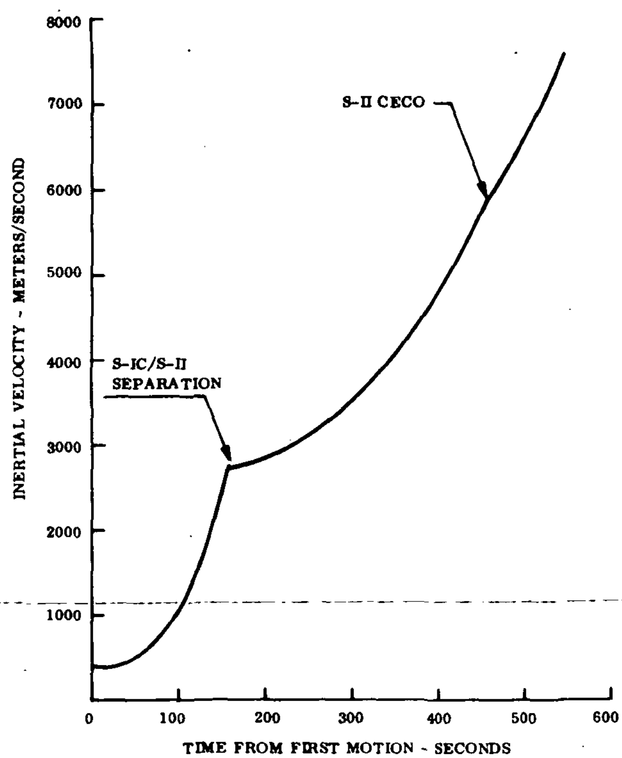


Figure 7-2. Inertial Velocity History During Boost to Orbit

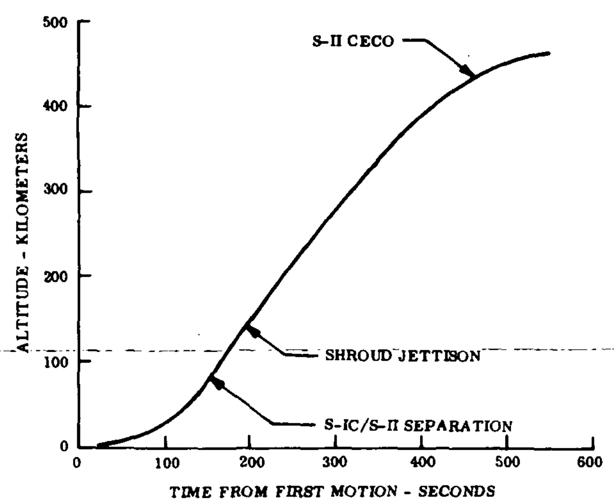


Figure 7-4. Inertial Flight Path Angle History During Boost to Orbit

Table 7-2. Critical Flight Parameter Summary

Parameter	Time (Sec)	Parameter Value
Maximum Aerodynamic Axial Force - Newton	68	1.36×10^6
Maximum Dynamic Pressure - Newton/m^2	74	33,543
Maximum Longitudinal Acceleration - g's	139	4.39
Aerodynamic Heating Indicator (AHI) at S-IC/S-II Separation - Newton/m (radiated area)	159	5.32×10^8
Dynamic Pressure at S-IC/S-II Separation - Newton/m^2	159	8
Dynamic Pressure at S-IC/S-II Forward Interstage Drop - Newton/m^2	189	0.02
Dynamic Pressure at Payload Enclosure Jettison - Newton/m^2	195	0.01

7.1.3 PHASE 3.0 ORBITAL OPERATIONS

Docking of the PM with the Base will be followed by a manual IVA (2-man operation) connection of the electrical and control circuits at the boom interface. The PM circuits are then monitored in the control room and continuity checks are made. PM systems are activated with auxiliary power. PM systems functional tests are made and instrumentation systems are verified operable. Control system operation is verified, and interlocks (if provided) are removed to allow control drums to assume pre-startup positions. Functional tests of the power distribution and conditioning systems are performed with auxiliary power. These PM readiness tests should require less than four hours for each reactor and would be performed from the control module. When readiness is achieved, the PM booms are extended into the normal operating position.

The initial start-up of the individual nuclear PM units will be performed immediately after checkout and communications tests. The startup sequence is performed after the booms have been extended with the thermal shrouds around the radiator. The automatic sequence is initiated from the control room with the sending of the reactor coded and sequenced start command. A controlled speed stepping sequence individually single steps the drums in sequential order. As criticality approaches, as planned into the program, the stepping speed is reduced; the reactor brought slowly through criticality and up to operating temperature and power, as described in Section 2. Current operating conditions are controlled by temperature measurements of the working fluid. The reactor is not designed to be load following. It will operate at the designated 330 kWt condition regardless of the electrical power drain. Power for these start-up operations comes from the Space Base auxiliary power system. The thermal shroud is incrementally retracted as fluid temperature is attained. The entire start-up sequence requires about 4 hours, with an additional 4 hours allocated for system stability. Start-up of both reactors can be accomplished within a 12-hour period.

Switch-over from auxiliary to reactor power will allow the reactors to assume the electrical load of the Space Base and the initiation of additional experimental activities. Roll-up of the solar array power system is accomplished after stabilization is achieved. Full power operation of over 50 kWe is not required immediately but is built up as the Base is expanded. (Power requirements are increased from approximately 40 kWe initially to a nominal 100 kWe when fully operational capability is achieved. During this entire time period, each reactor is operating at 330 kWt; however adjustments in the gas management system can be made for long off-power operations. During normal operations, only limited monitoring of the PM is required which can be done from the base or the MCC. These operations can be performed periodically or on command by an onboard checkout and monitoring system. A degree of fault isolation will be provided via instrumentation to enable the crew to rapidly diagnose and correct the situation. The most important function of the onboard systems is to monitor life and mission-critical functions continuously to provide advanced warning and allow for maintenance preparations. Immediate and in some instances automatic corrective actions such as PM shutdown should also be provided if conditions arise which cannot wait for crew intervention.

Planned PM shutdowns require several steps including the activation of the back-up solar array power system. The shutdown commands to the reactor cause the control drums to step outward at the 3-second stepping rate. The neutron radiation drops to about 1 percent in 3 minutes at this rate and in about an hour, the reactor coolant temperature will have dropped to below $425^{\circ}K$ ($300^{\circ}F$). The reactor radiator thermal shrouds are then repositioned around the radiator to prevent NaK freezing.

7.1.4 PHASE 4.0 REACTOR PM DISPOSAL

At the end of the normal lifetime of the reactor or after any accident which permanently or severely damages the reactor or power conversion system, the PM will be boosted to a 990 km (535 nm) disposal altitude where the fission product inventories will be allowed to decay to acceptable levels over a minimum 250 year long-life orbit prior to eventual re-entry. A complete description of the reactor disposal system is given in Section 3.

Figure 7-5 illustrates the maneuver used to place the reactor power module in the disposal orbit. Figure 7-6 shows the nominal sequence of events required for checkout, separation, and orbit transfer. The on-board checkout system will provide confirmation of reactor shutdown and system status. The PM is then separated from the Base at approximately 0.6m/sec (2 ft/sec) by a spring-eject system. The PM guidance and control system will orient the vehicle for the rocket burn. When the preselected separation distance of several kilometers is attained, the rockets are fired by remote control from the Base, the MCC providing a backup capability. The reliability of subsystem components for successful completion of the disposal operations is as follows (Reference 7-1):

Structural and Passive Temperature Control	.999999
Separation	.999600
Reaction Control System	.997526
Main Propulsion*	.999976
Guidance and Control	.998806
Electrical Power	.999941
Tracking Transponder	.999874
Telecommunications and Checkout	.998320

*(for 3 of 4 engines; one engine - .997993)

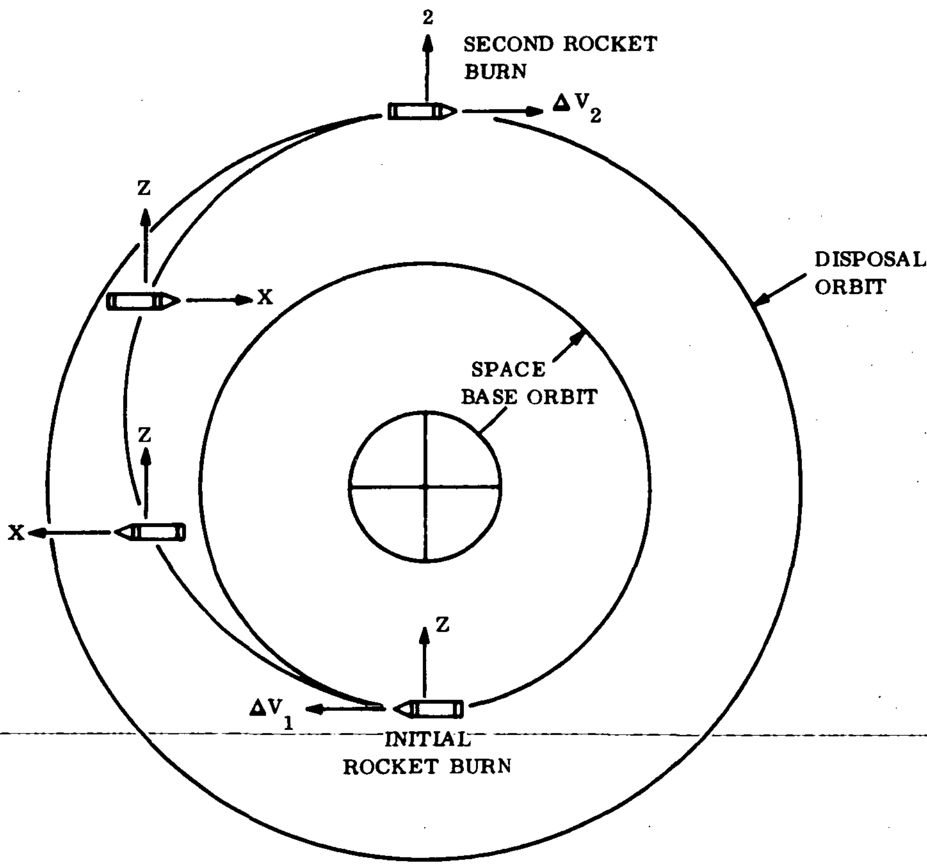


Figure 7-5. Orbital Transfer Maneuver

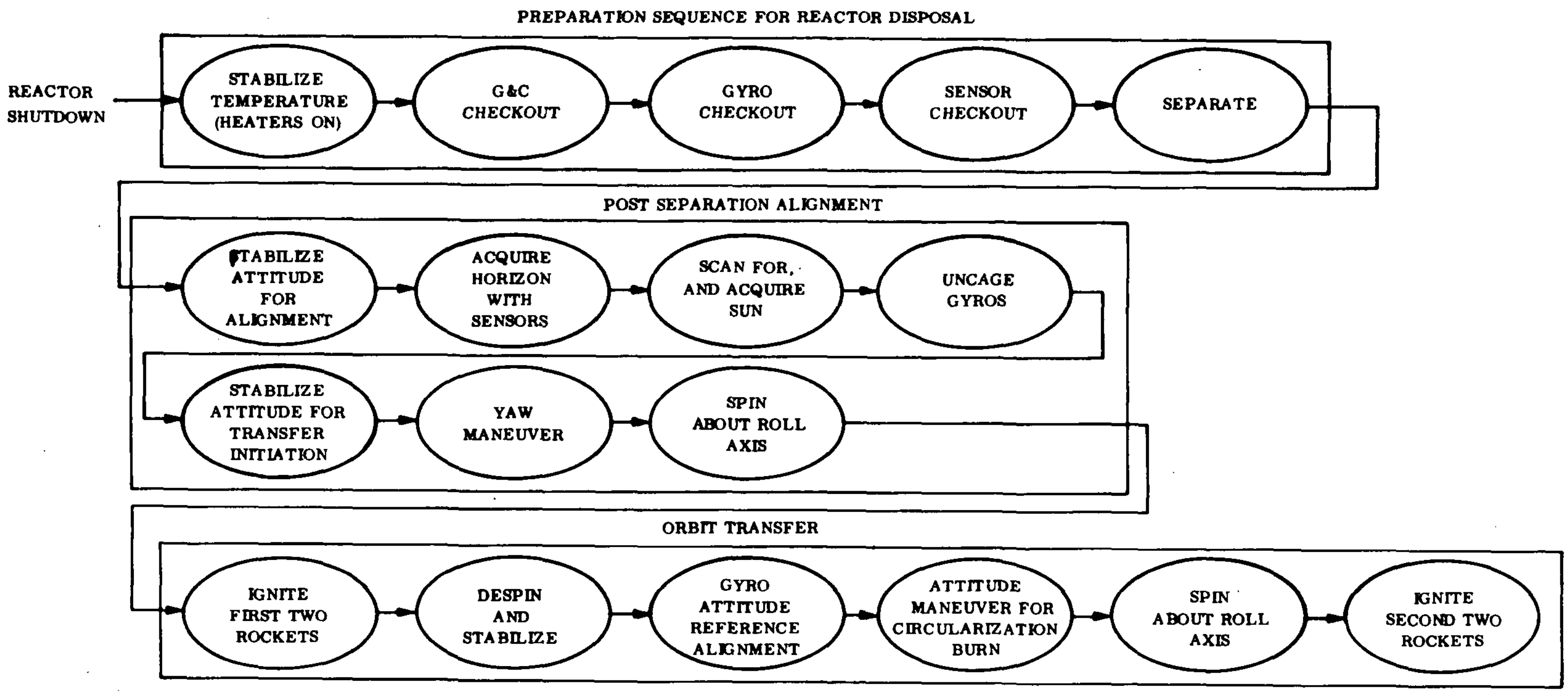


Figure 7-6. Disposal Operations

7.2 REFERENCES

7-1 "Operational Flight Analysis - INT 21 - Task 23," OFA-H-760, Boeing Company, October 1970.

7-2 "Preliminary Reference Design Document - Reactor," Volume II, MDC GO744, McDonnell Douglas, January 1971.

7-3 "Post Operational Safety of Reactor Power System for NASA Space Station," Volume V, Nuclear Power System Disposal Methods, AI-AEC-MEMO-12917, Atomics International, North American Rockwell, June 1970.

APPENDIX A

PRELIMINARY SELECTION OF THE REACTOR ORBIT DISPOSAL ALTITUDE

KEY CONTRIBUTORS

J.A. GARATE
W.W. PHELAN

APPENDIX A
PRELIMINARY SELECTION OF THE REACTOR ORBIT DISPOSAL ALTITUDE

The reactor disposal altitude was not specified and it was therefore necessary to select a desirable disposal altitude for purposes of the study. However, it immediately became apparent that the altitude would have a significant effect on the radiological risk to the public, and that the selection of a safe reactor disposal altitude should be based primarily on terrestrial safety considerations in order to minimize this risk. The risk to the public arises from a variety of potential accident situations which could occur during the disposal phase of the mission and lead to premature reentry of the nuclear system. The degree of risk incurred will be a function of fission product inventory, component reliabilities, and the orbit life time.

A.1 APPROACH

Normally, the propulsion system ΔV requirements are established by the desired disposal altitude and the transfer maneuver. However, all four rocket motors in the baseline propulsion system must function normally in order to achieve the desired orbit. If any of the motors fail to fire, the reactor will be left in a lower energy orbit than desired, generally elliptical, resulting in premature* reentry. The hazard, or risk, to the populace will depend upon the orbit lifetime, hence orbital characteristics of the reactor. Thus, it is desirable to size the propulsion system such that credible aborts during the disposal sequences result in "safe" or at least "acceptable" reactor orbits.

Various combinations of rocket motor failures were identified and calculations were performed to determine the resulting orbits and reentry decay times. These calculations were repeated for the various size disposal packages illustrated in Table A-1. This table shows the propulsion requirements for various disposal altitudes, assuming a Hohmann transfer from a base in a 500 kilometer orbit.

*Here, "premature" means any reentry other than decay from the nominal disposal orbit.

Table A-1. Disposal Package Velocity Requirements

Desired Disposal Altitude km	Desired Disposal Altitude nm	ΔV_1 m/sec	ΔV_2 m/sec	Total m/sec
648	350	39	39	78
694	375	51	51	102
740	400	64	63	127
833	450	88	87	175
926	500	112	110	222
1019	550	137	133	270
1111	600	159	155	314
1204	650	182	177	359
1296	700	204	198	402

Conditions

- Hohmann transfer from 500 km (273 nm)
- ΔV_1 = burn for transfer
- ΔV_2 = burn for circularization

The orbits and decay reentry times for various combinations of engine failures are shown in Table A-2. The decay reentry calculations were performed for two reentry configurations: (1) the entire reactor power module, which includes the radiator, propulsion systems, etc. (β = 1915 Newton/m^2, 40 lb/ft^2); and (2) the reactor with shield configuration (β = 16,858 Newton/m^2, 352 lb/ft^2). For example, assuming the propulsion system is sized to place the reactor PM in a 926 km (500 nm) orbit, then Table A-2 shows that if two motors fire at transfer (ΔV_1 = 112 m/sec, 367 ft/sec), and then one motor fails at apogee (ΔV_2 = 1/2 x 110 = 55 m/sec = 181 ft/sec), the reactor will be left in a 926 x 713 km elliptical orbit. The decay time of the PM configuration will be 73 years, and for the reactor/shield configuration the decay time will be about 646 years.

Table A-2. Decay Time from Orbit

Case	Success Reactor Placed in Desired Circular Orbit: Orbit km (nm)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$	2 Motors Fire at Transfer and 1 Motor Fails at Apogee: Orbit (km)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$	2 Motors Fire at Transfer and 2 Motors Fail at Apogee: Orbit (km)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$	1 Motor Fails at Transfer and 2 Motors Fail at Apogee: Orbit (km)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$	1 Motor Fails at Transfer and 1 Motor Fails at Apogee: Orbit (km)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$	1 Motor Fails at Transfer and 2 Motors Fire at Apogee: Orbit (km)	Decay Time (yrs) $\beta = 1915$	Decay Time (yrs) $\beta = 16,858$
1	500 (273)	4.8	43	-	-	-	-	-	-		-	-	-		-	-		
2	648 (350)	24	215	648 x 576	12	110	648 x 500	7.5	67	576 x 500	5.8	51	576	11	95	648 x 576	12	110
3	694 (375)	41	363	694 x 600	17	150	694 x 500	8.9	79	600 x 500	6.3	56	600	14	123	693 x 600	17	149
4	740 (400)	70	612	740 x 622	23	203	740 x 500	11	93	622 x 500	6.8	60	622	18	159	740 x 622	23	202
5	833 (450)	198	1743	833 x 667	42	3167	833 x 500	14	124	667 x 500	8.1	71	667	30	263	832 x 667	41	363
6	926 (500)	564	4963	926 x 713	73	646	926 x 500	18	160	711 x 500	9.5	84	711	49	434	922 x 711	72	638
7	1019 (550)	1606	14,130	1019 x 757	127	1116	1019 x 500	23	199	756 x 500	11	98	756 x 754	81	710	1015 x 756	125	1097
8	1111 (600)	4571	40,226	1111 x 802	215	1893	1111 x 500	27	242	800 x 500	13	112	800 x 803	131	1157	1106 x 800	210	1852
9	1204 (650)	13,013	114,516	1204 x 845	359	3163	1204 x 500	33	287	845 x 500	15	128	845 x 841	213	1874	1200 x 845	350	3080
10	1296 (700)	37,050	326,039	1296 x 889	593	5219	1296 x 500	38	335	887 x 500	16	144	887 x 882	343	3018	1285 x 887	575	5057

From inspection of Table A-2 it is obvious that for a given reentry configuration the abort reentry time varies considerably, depending upon the specific failure postulated. In some cases the reentry time is very short. In order to select the propulsion system requirements, it is necessary to first determine (1) an acceptable decay time for the fission products, and (2) the credible accidents to be protected against. From a preliminary analysis of the reactor fission product decay, it was determined that approximately 100 years of fission product decay will reduce the risk to the general public to negligible levels.

Since aborts are random in nature, the probability of each accident must be considered. Assuming that risk is proportional to decay time, then the disposal sequence can be made safer by increasing the average abort decay time to 100 years. That is,

$$\overline{Y} = \frac{\Sigma P_i \cdot Y_i}{P}$$

where

$\overline{Y}$ = average decay time (years)

Y_i = decay time resulting from accident (i)

P_i = probability of accident (i)

P = total abort probability

The summation is over all accidents.

Calculations were made to determine Y for each of the ten disposal cases in Table A-2. Since the reliability for one rocket motor is 0.997993, it follows that the

probability that both FIRE = R_1^2 = 0.995990 (SUCCESS)

probability that both FAIL = $(1 - R_1)^2 = 4.03 \times 10^{-6}$

probability that ONE FAILS = $2 R_1 (1 - R_1) = 4.01 \times 10^{-3}$

A sample calculation for Case 7 is shown in Figure A-1. The average decay time as a

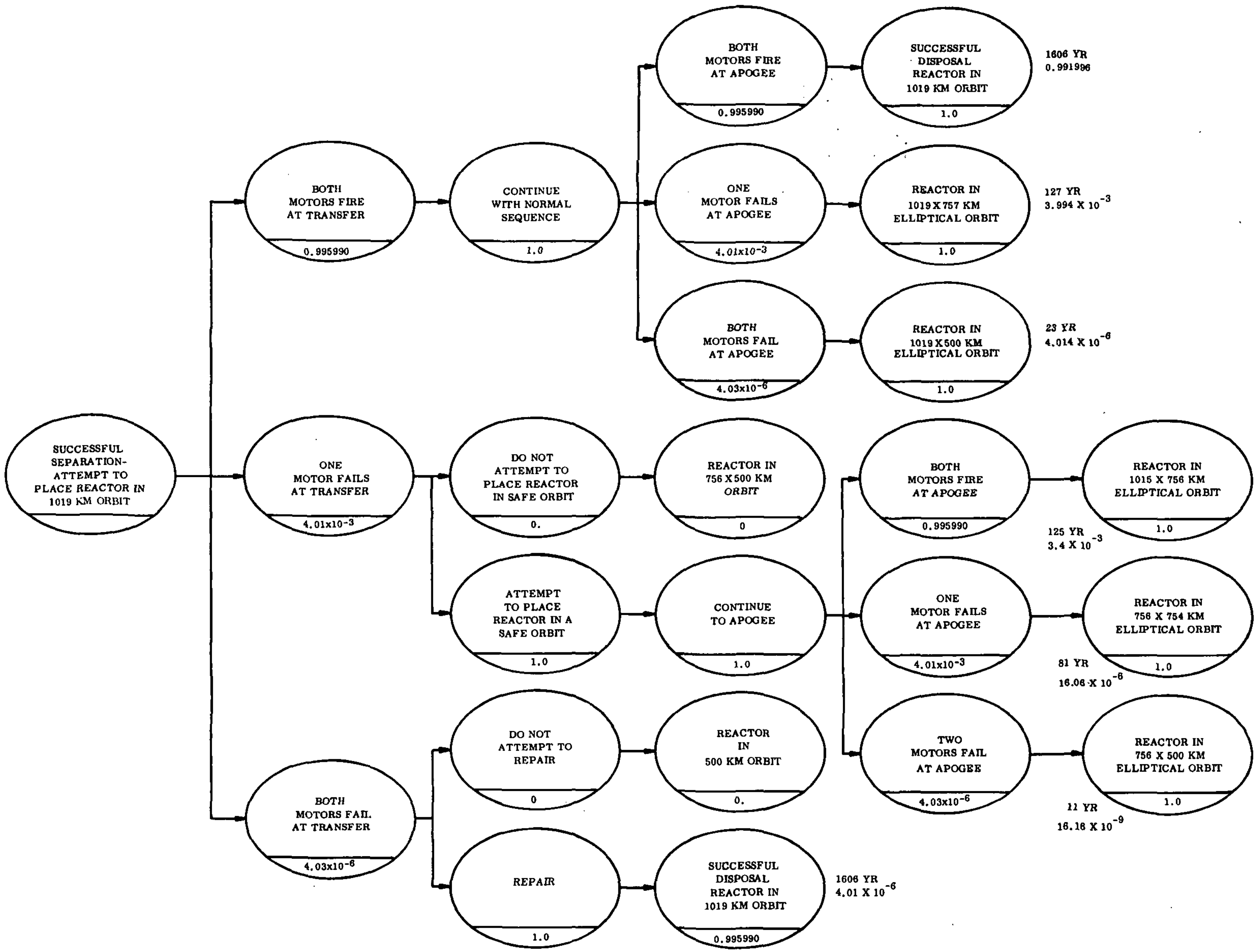


Figure A-1. Sample Calculation for Case 7 function of disposal orbit is shown in Figure A-2, where it can be seen that a disposal orbit of 990 kilometers yields an average decay time of 100 years. This altitude (990 km) then is the minimum disposal altitude required to minimize risk and has therefore been selected as the reference altitude for this study. A summary of the key parameters for the reactor disposal sequence is shown in Table A-3.

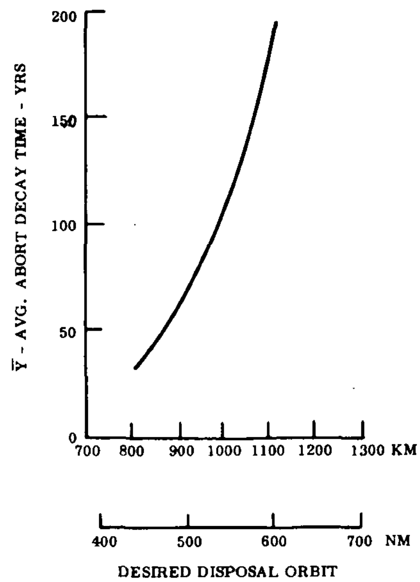


Figure A-2. Average Abort Decay Time as as Function of Desired Disposal Altitude

Table A-3. Summary of Key Parameters for Reactor Disposal Sequence

• Reactor Disposal Altitude		990 km (535 nm), Circular
• Minimum Orbit Decay Time from 990 km		1167 Years
• ΔV Required: (From 500 km to 990 km)		
	First Burn	129 m/sec
	Second Burn	126 m/sec
	Total	255 m/sec
• Propulsion System Probabilities		
	That 2 of 2 Fire	0.995990
	That 2 of 2 Fail	4.03×10^{-6}
	That 1 of 2 Fail	4.01×10^{-3}

A.2 MAJOR ASSUMPTIONS USED IN THE ORBITAL DISPOSAL ALTITUDE ANALYSIS

Perhaps the one assumption which has the greatest effect on the analysis is the model used for the calculation of the time required for decay from earth orbit. There appear to be many models available, some accounting for variations in solar activity, and some not. It was not possible for this study to determine the most appropriate model; hence, the most conservative was selected. This has the effect of overestimating the required disposal altitude and underestimating the orbital decay times.

The second most important assumption is that a fission product decay time of 100 years, following reactor shutdown, will reduce the risk to the general public to acceptable levels. This, however, is a simplifying assumption and should be replaced by a detailed radiological risk assessment.

Only rocket motor failures have been considered in this analysis, which is believed sufficient for a preliminary orbit estimate. To refine the calculation, subsequent iterations should be carried out using the detailed mission abort sequence trees.

It has been assumed in the analysis that the propulsion system consist of two groups of rocket motors, with two motors in each group (4 motors total). It is further assumed that if one rocket motor fails, a motor from the other group cannot be cut in to take over the functions of the failed motor. This was mainly a simplifying assumption, but other design concepts could be investigated by the same techniques discussed herein, if desired.

It is assumed that the disposal vehicle is sufficiently spin stabilized to allow asymmetrical burns of the rocket motors.

APPENDIX B
FUNCTIONAL DESCRIPTIONS

KEY CONTRIBUTORS

A. CARUVANA
J.A. GARATE
R.J. SPERA

APPENDIX B
FUNCTIONAL DESCRIPTIONS

Many of the systems and components which comprise the Space Base Program are only defined to a Phase A level of detail. Without a complete detailed description of all system components it is difficult to adequately define those accident situations which involve the interaction of various complex pieces of equipment. Functional descriptions of the most important systems in the Program were therefore prepared in order to reveal system interfaces which have a direct bearing on nuclear safety. Where appropriate, accidents have been described in terms of equipment functions which are lost. The following systems were analyzed:

Space Base (Reactor Power Module):

1. Electrical Power System (EPS)
2. Electrical Power Distribution System (some components could be located within the Space Base modules)
3. Reactor Disposal System

INT-21 Launch Vehicle

1. S-IC Stage
2. S-II Stage
3. Instrument Unit/Propulsion Module

A complete summary of the components and their principal functions is given in Table B-1.

Table B-1. Functional Description - Electrical Power System and Launch Vehicle

System		Sub-System	Major Functions
1. Electrical Power System	1	Reactor Primary NaK Loop	Power Generation Containment of Activated Coolant Containment of Fission Products
	2	Reactor Intermediate NaK Loop	Prevent Radioactive Contamination of Brayton Loop Transfer of Energy from Primary Loop to Brayton Loop
	3	Brayton Power Conversion Loop (3)	Conversion of Thermal Energy to Electrical Energy
	4	Brayton Heat Rejection Loop (3)	Rejection of Waste Heat
	5	Structures	Transmission of Loads
Sub-System		**Component**	**Functions**
1.1 Reactor Primary NaK Loop	1	Reactor	Production of Thermal Energy Secondary Barrier for Containment of Fission Products
	2	Primary Heat Exchanger	Transfer of Heat to Intermediate Loop Containment of NaK Coolant, Released Fission Products
	3	Primary Coolant Pump	Coolant Circulation Containment of Nak Coolant, Released Fission Products
	4	Primary Coolant Expansion Compensator (Accumulator)	Storage of Excess Coolant Coolant Pressurization Accommodation of Coolant Thermal Expansion
	5	Primary Coolant	Energy Transport Decay Heat Removal
	6	Flow Meter	Measurement of Primary Coolant Flow
	7	Primary Piping	Secondary Barrier for Containment of Fission Products Controls Exchange of Heat Primary Containment of Activated NaK Coolant
	8	Valves	Isolation of System Components
	9	Insulation	Minimize Heat Losses
	10	Stand-By Primary Coolant Pump	Back up Pump for Coolant Circulation Containment of NaK Coolant, Released Fission Products
	11	Special Instrumentation	Measurement of Coolant Temperature and Pressure Measurement of Primary Pump Temperatures
	12	Radiation Shield	Shielding of Nuclear Radiation Re-Entry Protection
	13	Reactor Control System	Control of Excess Reactivity Positive Reactor Shutdown Reactor Control at Power Control of Reactor Start-Up and Shutdown

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

Component		Sub-Component	Functions
1.1.1 Reactor	1	Core Vessel	Structural Support Primary Containment of Activated NaK Coolant Secondary Barrier for Fission Product Containment
	2	Fuel Elements	Primary Containment of Fuel and Fission Products Source of Energy Retention of Moderator
	3	Flow Baffles	Support Fuel Elements Maintain Element Spacing
	4	Internal and External Stationary Reflectors	Control of Neutron Population
	5	Primary Coolant	Transfers Energy from Reactor to PCS Source of Reactivity Provides Temperature and Power Level Control Function
1.1.12 Radiation Shield	1	Tungsten	Gamma Shield Thermal Shield Reactor Structural Support Secondary Containment of Activated NaK Coolant Re-Entry Protection
	2	Lithium Hydride (L_1H)	Neutron Shield Re-Entry Protection
	3	L_1H Can/Shell	Containment and Pressurization of Lithium Hydride Containment of Free Hydrogen Meteoroid Armor
	4	Depleted Uranium	Gamma Shielding Activated NaK Coolant Shielding Structural Support for Reactor-Shield Assembly Meteoroid Armor Blast and Fragmentation Protection Re-Entry Protection
1.1.13 Reactor Control System	1	Rotating Reflectors (Control Drums)	Adjustable Reflection of Neutrons
	2	Drum Position Sensors	Indication of Angular Orientation of Drums Secondary Check for Automatic Controller Indication of Core Lifetime
	3	Automatic Controller	Perform System Readiness Checks, Prior to Start-Up Perform Start-Up Maintain Steady State Power Level Perform Normal Shutdown Interpret System Process Data Provides Signals for Emergency Reactor Shutdown
	4	Reactor Instrumentation	Measurement of Reactor Coolant Temperature Measurement of Reactor Coolant Pressure Measurement of Reactor Flux (If Required)

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

Sub-System		Component	Functions
1.2 Reactor Intermediate NaK Loop	1	Heat Source Heat Exchanger (3)	Transfer Energy from Intermediate to Brayton Loop Maintain Pressure Differential between Loops Containment of Coolant
	2	Coolant Pump	Coolant Circulation (NaK) Coolant Containment
	3	Expansion Compensator (Accumulator)	Storage of Excess Coolant Coolant Pressurization Accommodation of Coolant Thermal Expansion
	4	Coolant	Energy Transport
	5	Coolant Piping	Coolant Containment Secondary Barrier for Activated Coolant Containment Tertiary Barrier for Fission Product Containment
	6	Valves	Isolates Redundant PCS Loops Isolates Failed Heat Source Heat Exchanger
	7	Stand-By Coolant Pump	Back-Up Pump for Coolant Circulation
	8	Insulation	Minimize Heat Losses
	9	Special Instrumentation	Measurement of Int. Loop Temperature and Pressure Measurement of Int. Loop Coolant Pump Temperature
1.3 Brayton Power Conversion Loop	1	Turbine-Alternator-Compressor	Convert Thermal Energy to Electrical Energy Gas Circulation Gas for Gas Bearings Sealing of High Pressure Gas in Compressor Sealing of High Temperature Gas in Turbine Containment of He-Xe Gas
	2	Heat Source Heat Exchanger	Transfer of Energy from Intermediate to Brayton Loop Barrier between Intermediate Loop Coolant and Brayton Gas Containment of Intermediate Loop Coolant Containment of Brayton Loop Gas
	3	Waste Heat Heat Exchanger	Transfer of Energy from Brayton to Heat Rejection Loop Barrier between Brayton Gas and Heat Rejection Loop Coolant Containment of Brayton Loop Gas Containment of Heat Rejection Loop Coolant
	4	Gas-Management System	HeXe Gas Storage Charges Brayton Loop with Gas During Start-Up Provides Make-Up Gas During Operation Vents Gas from Brayton Loop During Shutdown Regulates Gas Inventory in Brayton Loop During Power Changes
	5	Recuperator	Recovers Portion of Turbine Exhaust Heat Separates High and Low Pressure Sections of Brayton Loop Containment of Brayton Loop Gas

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

Sub-System		*Components*	Functions
1.3 Brayton Power Conversion Loop (Continued)	6	HeXe Gas	Brayton Cycle Working Fluid Energy Transport
	7	Insulation	Minimize Heat Losses
	8	Brayton Instrumentation	Monitor Gas Temperature and Pressure Monitor Frequency, Voltage and Current (Electrical Output) Monitor Alternator Temperatures Monitor TAC Gas Bearing Temperature and Pressure
	9	Bypass Valve	Emergency Turbine Overspeed Protection Backup Regulation of Electrical Power Frequency
	10	Brayton Control System	Control of Brayton Machinery
	11	Back-Up Systems (2) ● TAC ● HS HX ● WH HX ● Gas Management ● Recuperator	Replacement Unit (Replace Operating Unit in ≈ 2 1/2 Years) Emergency Unit (Back-Up for Replacement Unit)
Component		Sub-Component	Functions
1.3.10 Brayton Control System	1	Sensing Circuits	Combines Voltage and Current Measurements for Frequency Sensing Provides Firing Circuits for Controlled Rectifiers Compares Measured and Desired Frequency
	2	Switching Distribution Circuit	Switches Excess Power to Parasitic Load Resistors
	3	Parasitic Load Resistor	Rejection of Plant Excess Energy
Sub-System		Component	Functions
1.4 Brayton Heat Rejection Loop	1	Primary Heat Rejection Loop	Rejection of Primary Systems Waste Heat
	2	Auxiliary Heat Rejection Loop	Rejection of Auxiliary Systems Waste Heat
Component		Sub-Component	Functions
1.4.1 Primary Heat Rejection Loop	1	Primary (NaK) Radiator	Waste Heat Dissipation Meteoroid Armor Protection Structural Support for Power System Protective Volume for Power System Components Coolant Containment Blast/Fragment Protection
	2	Radiator Coating	Provides High Emissivity Surface
	3	NaK Coolant	Waste Energy Transport
	4	Coolant Pump (Centrifugal)	Coolant Circulation Coolant Containment
	5	Piping	Coolant Containment
	6	NaK Expansion Compensator	Storage of Excess Coolant Coolant Pressurization Accommodation of Coolant Thermal Expansion

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

Component		Sub-Component	Functions
1.4.1 Primary Heat Rejection Loop (Continued)	7	Thermal Shroud	Prevents Freezing of Radiator Coolant Prior to Start-Up Prevents Freezing of Radiator Coolant During Shutdown
	8	Radiator Control Instrumentation	Monitor Radiator Coolant Temperature and Pressure Monitor Coolant Pump Temperature
1.4.2 Auxiliary Heat Rejection Loop	1	Auxiliary (Organic) Radiator	Dissipation of Auxiliary Systems Waste Heat Meteoroid Armor Protection Structural Support for Power System Coolant Containment Blast/Fragmentation Protection
	2	Radiator Coating	Provides High Emissivity Surface
	3	Coolant	Waste Energy Transport
	4	Coolant Pump (Centrifugal)	Coolant Circulation Coolant Containment
	5	Piping	Coolant Containment
	6	Organic Expansion Compensator	Storage of Excess Coolant Coolant Pressurization Accommodation of Coolant Thermal Expansion
	7	Cold Plates	Cooling of: Primary Pump; Intermediate Loop Pump; Alternator; TAC Bearings; Engine Control Electronics; Electrical Control Electronics Coolant Containment
	8	Thermal Shroud	Prevents Freezing of Radiator Coolant During Shutdown
	9	Radiator Control Instrumentation	Monitor Coolant Temperature and Pressure Monitor Coolant Pump Temperature
Sub-System		**Component**	**Functions**
1.5 Structures	1	Reactor Support Structure	Transmission of Reactor Mechanical Loads to Shield Assembly
	2	Shield Support Structure	Framework for Gamma and Neutron Shielding Transmission of Reactor and Shield Loads to Power System Structure
	3	Power System Structure	Framework for Power System Component Attachment Transmission of Power System Loads to Boom Attachment of Power System to Boom
	4	PCS Support Structure	Framework for Attachment of PCS Components Transmission of PCS Loads to Power System Structure
	5	Pipe Hangers	Support of Loop Piping Transmission of Coolant Loop Loads to Power System Structure
	6	Boom	Mechanical Connection Between EPS and Space Base Physical Separation Between EPS and Space Base

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

System		Sub-Systems/Components	Functions
2. Electrical Power Distribution System	1	Power System Computer	Switches Bus Configuration for Load Control of Individual Alternators Commands Secondary Distribution Decoders for Switching of Individual Loads
	2	Voltage Regulator Exciter	Regulated Field Excitation to Alternator Limits Any Phase Voltage to 110% of Normal in Event of Open or Short in Phase
	3	Main Load Power Conditioning	Provides Circuit Protection Against Failure Measures Power Being Generated and Used If DC Distribution, Rectifies and Filters 3ϕ Output
	4	Hotel Load Power Conditioning	Provides Circuit Protection Against Failures Supplies Power to Power System Pumps, Reactor Actuators, Reactor Control Circuit Provides Electrical Switching for Redundant Power System Components
	5	Main Load Emergency Power	Provides Battery/Solar Array Power for Short/Long Power Failures Regulates Battery Discharge Provides Switching for Emergency Power Use
	6	Hotel Load Emergency Power	Provides Battery Power and Recharge for Hotel Load Circuit Failures Provides Switching for Emergency Power Use
	7	Transmission Busses	Distributes High Voltage Power to Secondary Distribution Centers
	8	Slip Rings	Transfers Power Across Rotating Joints
	9	Secondary AC Distribution Center	
	10	Secondary DC Distribution Center	
Sub-System		**Component**	**Functions**
2.9 Secondary AC Distribution Center	1	Autotransformer	Conditions Power to User AC Voltage
	2	Rectifiers-Filters	Provides Power to DC Loads
	3	Command Decoder	Switch Power to Load on Command of Computer
	4	Distribution Busses	Deliver Power from Distribution Center to Loads
2.10 Secondary DC Distribution Center	1	Inverters	Provide Power to AC Loads
	2	Converters	Provide Power to Low Voltage DC Loads
	3	Command Decoders	Switch Power to Load on Command of Computer
	4	Distribution Busses	Deliver Power from Distribution Center to Loads
System		**Sub-Systems/Components**	**Functions**
3. Reactor Disposal System	1	Structural and Passive Temperature Control	Docking and Release Mechanisms EPS Interface Control Component Temperatures
	2	Separation	Separate PM from Space Base
	3	Reaction Control System	Spin Stabilization of PM Pitch, Yaw, Roll Control
	4	Main Propulsion	Provide Thrust at Transfer and Circularization

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

System		Sub-Systems/Components	Functions
3. Reactor Disposal System (Continued)	5	Guidance and Control	Attitude Control Sensing and Logic Firing Commands
	6	Electrical Power	Electrical Power Generation and Distribution
	7	Transponder	Allows Tracking of PM After Separation from the Base
Launch Vehicle		**Major Systems**	**Functions**
INT-21 Launch Vehicle	1	S-IC Stage	Provides First Stage Boost of INT-21
	2	S-II Stage	Provides Second Stage Boost of INT-21
	3	Instrument Unit/Propulsion Module	Rendezvous with the Space Base or Space Tug Docking Velocity
Major Systems		**Systems/Sub-Systems**	**Functions**
1. S-IC Stage	1	Structural Systems	Transmission of Launch Loads Containment of RP-1 and LOX
	2	Environmental Control System	Protects S-IC Stage from Temperature Extremes, Excess Humidity and Hazardous Gases During Prelaunch
	3	Propulsion System	Stage Thrust, Single Start Thrust Vector Control
	4	Flight Control System	Attitude Control
	5	Penumatic Control System	Control and Actuation of Various Valves During Flight (Fuel and LOX Prevalves and Vent Valves)
	6	Propellant System	Supply Fuel (RP-1) and Liquid Oxygen (LOX) to F-1 Rocket Engines Tank Pressurization, Fuel Fill and Drain
	7	Electrical System	Supplies Power to Operational Loads Supplies Power to Measurement Loads including Telemetry Systems and Transmitters
	8	Instrumentation	Monitors Functional Operation of Stage Systems Provides Signals for Vehicle Tracking During S-IC Born Transmission of Data to Ground
	9	Ordnance System	Separation Thrust After S-IC Burnout Termination of Vehicle Flight During S-IC Boost
2. S-II Stage	1	Structural Systems	Transmission of Launch Loads Containment of Liquid Hydrogen and Liquid Oxygen
	2	Environmental Control System	Temperature Control and Purging of Launch Vehicle Compartments During Prelaunch Operations
	3	Propulsion System (5 J-2 Rocket Engines)	Stage Thrust Thrust Vector Control
	4	Flight Control System	Proper Control of Vehicle Pitch, Roll and Yaw Axes

Table B-1. Functional Description - Electrical Power System and Launch Vehicle (Cont'd)

Major Systems		Systems/Sub-systems	Functions
2. S-II Stage (Continued)	5	Pneumatic Control	Control and Actuation of Various Valves During Flight
	6	Propellant Systems	Supply Fuel and Oxidizer to the Five J-2 Rocket Engines Prepressurization of Propellant Tanks Propellant Recirculation, Management
	7	Electrical System	Provides Stage II Electrical Power and Distribution
	8	Instrumentation	Monitors and Measures Conditions on S-II Stage Transmits Measurements to the Ground
	9	Ordnance System	Stage Separation Termination of Vehicle Flight During S-II Boost
System/Subsystems			**Functions**
2.1 Structural System	1	Body Shell Structure	
	2	Thrust Structure	Transmission of Launch Loads Support System Components
	3	Propellant Tank Structure	Containment LH_2 and LO_2
	4	Systems Tunnel	Houses Electric Cables, Pressurization Lines and Tank Propellant Dispersion Ordnance
2.2 Environmental Control System	1	Thermal Control System	Thermal Control to FWD and Aft Skirt Mounted Equipment Containers During Prelaunch (Air, Gaseous Nitrogen)
	2	Engine Compartment Conditioning System	Purges the Engine and Interstage Areas of Explosive Mixtures Maintains Proper Temperature in Engine and Interstage Areas Minimizes Danger of Fire or Explosion Resulting from Propellant Leakage
	3	LH_2 Tank Insulation (Honeycomb)	Prevent Condensation on LH_2 Tanks Reduce Temperature Rise During Cryogenic Operations
	4	Purge and Leak Detection System	Provides a Flow of Helium through Honeycomb Insulation and Adjacent Areas to Exclude Hazardous Gases Sound Alarm if Hazardous Quantities of Hydrogen/Oxygen are Present
2.9 Ordnance System	1	Separation System	Initiate Stage Separation Ordnance Sever Tension Members between S-IC/S-II Stages
	2	Ullage Rocket System	Insures Stable Flow of Propellants into the J-2 Engines by Providing Small FWD Acceleration to Settle the Propellants in their Tanks (During Separation)
	3	Retrorocket System	Separate and Retard S-II Stage
	4	Propellant Dispersion System (PDS)	Provides for Termination of Vehicle Flight During S-II Boost Phase On Command from Range Safety Officer, the LH_2 and LOX Tanks are Cut Open by Linear Shaped Charge

Table B-1. Functional Description - Electrical Power System Launch Vehicle (Cont'd)

System		Sub-System	Functions
3. Instrument Unit/Propulsion Module	1	Maneuvering Engines	Provide Rendezvous and Docking Velocity Requirements
	2	Attitude Control Engines	Stabilization and Control of Payload Module Alignment of S-II Prior to Separation
	3	Propellant System	Supply Fuel to the Rocket Engines

CONVERSION FACTORS
INTERNATIONAL TO ENGLISH UNITS

Physical Quantity	International Units	English Units	Conversion Factor Multiply By
Acceleration	m/sec^2	ft/sec^2	3.281
Area	m^2	ft^2	10.764
		in^2	1550.39
Density	Kg/m^2	lb/ft^3	6.242×10^{-2}
		lb/in^3	3.610×10^{-5}
Energy	Joule	Btu	9.479×10^{-4}
Force	Newton	lbf	2.248×10^{-1}
Length	m	ft	3.281
		nm	5.399×10^{-4}
Mass	Kg	lbm	2.205
Power	watt	Btu/sec	9.488×10^{-4}
		Btu/min	5.691×10^{-2}
		Btu/hr	3.413
Pressure	$Newton/m^2$	Atmosphere	3.413
		lbf/in^2	1.451×10^{-4}
		lbf/ft^2	2.088×10^{-2}
Speed	m/sec	ft/sec (fps)	3.281
Temperature	K	F	$(9/5 - 459.67/t_K)$
Volume	m^3	in^3	6.097×10^4
		ft^3	35.335

GLOSSARY OF TERMS

Abort	Premature and abrupt termination of an event or mission because of existing or imminent degradation or failure of hardware. (In the safety analysis, no distinction is made between an accident and abort.)
Accident	An undesirable unplanned event which may or may not result from a system failure or malfunction.
Airborne Material	Radioactive gases, vapors and particulates released to the air.
Breached	Fuel elements, coolant loops, pressure vessel, core, or radiation shield are (a) physically torn by thermal or mechanical stresses, (b) cut open by fragmentation or (c) split open by internal pressures.
Bulk Damage (Radiation)	Radiation causing atomic displacement in semiconductor devices - sometimes commonly referred to as "crystal" damage.
Contamination	A condition where a radioactive material is mixed or adheres to a desirable substance or where radioactivity has spread to places where it may harm persons, experiments or make areas unsafe.
Control Drum Motion	Rotation of the control drums or drum toward or away from the most reactive position within a reactor. (As used in safety analysis results in a reactor excursion.)
Core Compaction	The act of increasing the density of the core which results in increased reactivity and possible criticality.
Cover Gas	A gas blanket used to provide an inert atmospheric environment around hardware to minimize potential reactions which can give rise to accident situations.
Credible	An event having a relative or cumulative probability of occurence of $> 10^{-12}$.
Criticality	The act of obtaining and sustaining a chain reaction.
Critical Mass	The mass of fissionable material necessary to obtain criticality.
Cumulative Probability	Sometimes referred to as "Mission probability" is the overall probability of a sequence of events occurring (product of "relative probabilities" of the individual events along a path of an abort sequence tree).
Damaged	Same as "Breached".
Decontamination	The removal of undesired dispersed radioactive substances from material, personnel, rooms, equipment, air, etc. (e.g., washing, filtering, chipping).
Destructive Excursion	An excursion (safety analysis assumes $\sim$ 100 MW-sec) accompanied by a complete disassembly of the reactor, a prompt radiation emission and release of fission product gases, vapors and particulates.
Disassembly/Disassembled	Nuclear hardware (e.g., reactor) which has been violently broken or separated into parts and not capable of forming a critical mass.
Disposal	The planned discarding or recovery of nuclear hardware.
Distributed Material	The spread of nuclear fuel and radioactive debris on the earth's surface following impact or destructive excursion.
Dose Guidelines	Established radiation levels used in the nuclear safety analysis for evaluating number of exposures and in determining operating limits and boundaries.
Dosimetry	Techniques used in the measurement of radiation.

GLOSSARY OF TERMS (CONT)

Dynamic Interference	An experiment radiation effect where the flux rate above some threshold (a fraction of the experiment signal-to-noise ratio at maximum sensitivity, for electronic detectors) causes noticeable degradation of data quality.
Early Reactor Disposal	Attempted disposal of the reactor prior to its successful completion of 5 years operational lifetime.
Electrical Power System	All components (heat source, regulation, control, power conversion and radiators) necessary for the development of electrical power. The reactor electrical power system includes all hardware associated with the Power Module with the exception of the Disposal System.
End of Mission	Generally associated with the termination of the mission or flight. Is also used to define those activities involved with disposal and recovery of hardware after intended lifetime.
Excursion	A rapid and usually unplanned increase in thermal power associated with the operation of a power reactor.
Exposure Limit	Total accumulated or time dependent radiation exposure limits imposed on personnel by regulatory agencies or limits which preclude equipment damage.
Fission Products	The nuclides (quite often radioactive) produced by the fission of a heavy element nuclide such as U-235 or Pu-239.
Fuel	Fissionable material in a reactor or radioisotopes in a heat source used in producing energy.
Fuel Element/Capsule	A shaped body of nuclear fuel prepared for use in a reactor or heat source. Common usage involves some form of encapsulation.
Fuel Element Ablation	Fuel element clad and/or fuel removed by reentry heating, releasing fission products to the atmosphere.
Fuel Element Burial	Individual fuel elements beneath the ground surface completely covered by soil.
Gallery	The compartment of the reactor shield which houses the major primary loop components.
Ground Deposited Particles	Particles deposited on the ground from radioactive fallout.
Hazard	An existing situation caused by an unsafe act or condition which can result in harm or damage to personnel and equipment.
Hazard Source	The location and/or origin of the hazard.
Immediate Reentry	Very early reentry of the reactor (e.g., misaligned thrust vector which causes firing of the reactor disposal rockets toward earth resulting in 1-2 day reentry).
Impact in Deep Ocean	Reentering and/or impact of nuclear material in the ocean, beyond the Continental Shelf where contamination of the food chain is extremely remote.
Impact in Reservoir	Reentering and/or impact of nuclear material in reservoir containing potable drinking water.
Impact in Water Containing Edible Marine Life	Reentering and/or impact of nuclear material on the Continental Shelf or in a body of water such as a lake, river or stream where contamination of the food chain is likely.
Intact Reentry/Reactor	A nuclear system that retains its integrity upon impact and in the case of a reactor is capable of undergoing an excursion.
Integrated/Cumulative Dose	The total dose resulting from all or repeated exposures to radiation.
Interfacing Vehicle	Any defined module, spacecraft, booster or logistic vehicle which may have an interaction with the Manned Space Base.

GLOSSARY OF TERMS (CONT)

Ionization Damage	Radiation causing surface damage in materials (e.g., the fogging of film).
Land Impact	Nuclear hardware which impacts land at terminal velocities following reentry and lower velocities during prelaunch or early in the launch/ascent phase.
Loss of Coolant	Loss of organic or liquid metal coolant in reactor coolant loops due to failure/accident.
Mission Support	Supporting functions provided the Space Base Program by ground personnel and interfacing vehicles throughout all mission phases.
Moderator	Material used in a nuclear reactor to slow down neutrons from the high energies at which they are released to increase the probability of neutron capture: Water and hydrogen are moderators in a thermal reactor.
NaK-78	An alloy of sodium (22% by weight) and potassium (78%) used as a liquid metal heat transfer fluid.
No Discernible Hazard	Represents no hazard to the general populace.
Non-credible	An event having a relative or cumulative probability of occurrence of $< 10^{-12}$. Considered not worthy of concern.
Non-destructive Excursion	A temperature excursion which may rupture the primary coolant loop and release fission products to the environment but - leaves the reactor shield essentially intact.
Normal Operations	Planned and anticipated mission activities and events.
Over Moderation	Immersion of reactor in an hydrogenous medium (moderator) resulting in increased neutron reflection into the core causing a reactor excursion.
Permanent Shutdown	Enacting provisions which preclude reactor criticality under all foreseeable circumstances.
Poison	A material that absorbs neutrons and reduces the reactivity of a reactor.
Power Module	The complete reactor/shield, radiator, power conversion system and disposal system unit as provided on the Space Base.
Premature Reentry	Any reentry of the reactor from Earth orbit with orbital lifetimes less than the planned (1167 year) orbital decay time of the 990 km disposal altitude.
Pre-poison	A poison which is added to the reactor fuel for purposes of controlling reacticity. Sometimes referred to as "burnable poison".
Prompt Radiation	The neutron and gamma radiation released coincident with the fission process as opposed to the radiation from fission product decay. Commonly associated with an excursion event.
Quasi-Steady State	A term used to describe the condition when a reactor periodically goes critical and then subcritical due to water surging in and out of the core.
Radiological Consequences	The radiation exposure effect on personnel and the ecology from a radiation release accident or event.
Radiological Hazards	Hazards associated with radiation as differentiated from other sources.
Radiological Risk	The term used to define the average number of people anticipated to be affected by radiation in a given mission or phase thereof.
Random Reentry	The uncontrolled non-directed reentry of a vehicle from orbit.
Reactivity	A measure of the departure of a reactor from critical such that positive values correspond to reactors super-critical and negative values to reactors which are sub-critical. (Usually expressed in multiples of a dollar.)

GLOSSARY OF TERMS (CONT)

Reactor Fails to Survive Reentry	Reactor/shield is completely disassembled by reentry heating, releasing individual fuel elements and structural debris to the atmosphere.
Reactor Survives Reentry	Reactor is not disassembled by reentry heating; radiation shield may be damaged.
Reactor/Shield	A system containing the reactor, control drums, gallery and surrounding LiH and Tungsten shield.
Relative Probability	Probability of the occurrence of a particular event given a defined set of choices.
Repair/Replacement	Consists of (a) physically repairing all faulty systems, or (b) complete replacement of the faulty system(s).
Ruptured	Same as "Breached".
Safety	Freedom from chance of injury or loss to personnel, equipment or property.
Safety Catastrophic	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will severely degrade system performance, and cause subsequent system loss, death, or multiple injuries to personnel (SPD-1A).
Safety Critical	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem or component malfunction will cause equipment damage or personnel injury, or will result in a hazard requiring immediate corrective action for personnel or system survival (SPD-1A).
Safety Marginal	Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will degrade system performance but which can be counteracted or controlled without major damage or any injury to personnel (SPD-1A).
Safety Negligible	Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure or component malfunction will not result in minor system degradation and will not produce system functional damage or personnel injury (SPD-1A).
Scram System	A separate, possibly automatic, mechanism used to rapidly shut down a reactor.
System Safety	The optimum degree of risk management within the constraints of operational effectiveness, time and cost attained through the application of management and engineering principles throughout all phases of a program.
Space Base Program	All aspects of the Space Base mission including all prime and support hardware and personnel both on the ground, at sea or in orbit, which are required throughout all mission phases.
Space Debris	Uncontrolled radioactive or non-radioactive man-made objects in space; these objects may present collision and radiation hazards to earth orbital missions.
Space Shuttle	The manned vehicle used for the transportation of cargo to and from earth orbit. A separately launched vehicle (booster) on which the Shuttle is placed provides the initial first stage thrust.
Source Terms	Characterization of a radiation hazard with regard to (a) location, (b) magnitude, and (c) exposure mode.
Tracer	Material in which isotopes of an element may be incorporated to make possible observation of the course of the element through a chemical, biological or physical process.

GENERAL ELECTRIC

Space Division / Headquarters: Valley Forge, Pennsylvania ☐ Daytona Beach, Fla. ☐ Cape Kennedy, Fla. ☐ Evendale, Ohio ☐ Huntsville, Ala. ☐ Bay St. Louis, Miss. ☐ Houston, Texas ☐ Newport Beach, Calif.